AFCRL-69-0017(I)

AD685183

TETHERED BALLOON HANDBOOK (REVISED)

Philip F. Myers

Goodyear Aerospace Corporation
Akron, Ohio 44315

Contract No. F19628-68-C-0311

Project No. 6665
Task No. 666507
Work Unit No. 66650701

Final Report

1 May 1968 - 31 December 1968

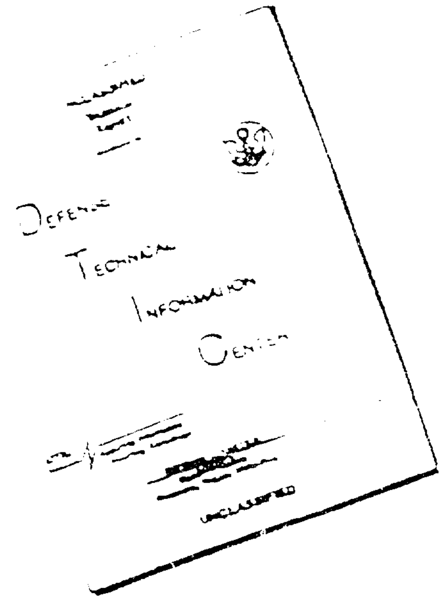
November 1969

Contract Monitor: Edward F. Young, Captain, USAF
Aerospace Instrumentation Laboratory

Prepared for

Air Force Cambridge Research Laboratories
Office of Aerospace Research
United States Air Force
Bedford, Massachusetts 01730

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the Clearinghouse for Federal Scientific and Technical Information.

AFCRL-69-0017(I)

TETHERED BALLOON HANDBOOK (REVISED)

Philip F. Myers

Goodyear Aerospace Corporation
Akron, Ohio 44315

Contract No. F19628-68-C-0311

Project No. 6665
Task No. 666507
Work Unit No. 66650701

Final Report

1 May 1968 - 31 December 1968

31 December 1968

Contract Monitor: Edward F. Young, Captain, USAF
Aerospace Instrumentation Laboratory

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

Prepared for

Air Force Cambridge Research Laboratories
Office of Aerospace Research
United States Air Force
Bedford, Massachusetts 01730

FOREWORD

This project was sponsored by the Office of Aerospace Research, USAF, and was monitored by the Air Force Cambridge Research Laboratories under Contract No. F19628-68-C-0311. The project was carried out under the direction of Captain Edward F. Young as Contract Monitor for the Air Force Cambridge Research Laboratories. Mr. Philip F. Myers was the Goodyear Aerospace Project Engineer. The contractor's report number is GER 14142.

ABSTRACT

The Tethered Balloon Handbook is a single volume reference covering the history, development, applications, and listings of available modern equipment for tethered balloon activities of an engineering or scientific nature.

(Page iv is blank)

TABLE OF CONTENTS

Section		Page
I	INTRODUCTION	1
	1. General	1
	2. Tethered Balloon History	1
	3. Shapes and Stability	8
	4. Pressure Systems	10
	5. Balloon System Operational Requirements	14
	6. Selecting a Balloon System	14
II	BALLOON SYSTEMS	15
	1. General	15
	2. Helium-Filled Balloon System	20
	3. Hydrogen-Filled Balloon System	22
	4. Other Gas-Filled Balloon Systems	22
	5. Hot-Air System	22
	6. Information Required by Balloon Contractor	23
	7. Available Balloon Systems	23
	8. List of Manufacturers	23
III	ENVELOPE MATERIALS	31
	1. General	31
	2. Fabrics	31
	3. Cloth	31
	4. Elastomers	35
	5. Fabric Construction	35
	6. Films	39
	7. Woven Cloths	39
	8. Coatings	40
	9. Diffusion and Infusion	41
	10. Testing Laminated Fabrics	41
	11. Testing Permeability and Ply Adhesion	41
	12. Available Envelope Materials	41
IV	LIFTING GASES	45
	1. General	45
	2. Aerostatics	45
	3. Types of Lifting Gases	47
	4. Balloon Displacement	49
	5. Computing Helium Requirements	51
	6. Computing Hydrogen Requirements	53
	7. Computing Hot Air Requirements	53
	8. Helium Repurification	58
	9. Helium Compressor, Electrical Driven	59
	10. Hydrogen Problems	59
	11. Hydrogen Generation	62
	12. General Safety Rules for Cylinders	65
	13. Safety Rules for Cylinders During Balloon Inflation	66
	14. Safety Rules for Cylinders Around Hydrogen Plants	67
V	WINCHES AND TETHERS	69
	1. Winches - General Description	69
	2. Types of Winch Installations	69
	3. Basic Winch Components	72
	4. AFCRL Holloman AFB Balloon Winches	79

Section		Page
	5. Available Winches	82
	6. Tethers - General Description	90
	7. Properties and Characteristics of Tethers	90
	8. Tether Materials	96
	9. Tether Length	97
	10. Tether Diameter	102
	11. Tether Construction	102
	12. Fittings	104
	13. Available Tethers	113
VI	BALLOON HANDLING	123
	1. General	123
	2. Balloon Handling Precautions	123
	3. Balloon System Operations	123
VII	INSTRUMENTATION	133
	1. General	133
	2. Temperature Sensors	133
	3. Pressure Transducers	133
	4. Accelerometers	134
	5. Load Cells	134
	6. Wind Speed and Direction	134
Appendix		
I	AEROSTATICS	143
II	HELIUM FACT SHEETS	154
III	TETHERED BALLOON SITES	167
	REFERENCES	198
	BIBLIOGRAPHY	199

LIST OF ILLUSTRATIONS

Figure		Page
1	Double Tethered Balloon, Early French, 1795	2
2	Lowe's Balloon Washington Aboard the Custis During American Civil War, 1861 (Smithsonian Institution)	3
3	German Drachen Towed by Torpedo Boat (Smithsonian Institution)	5
4	Handling a Balloon Aboard Navy Ship (Wingfoot Lighter-Than-Air Society Museum Collection)	6
5	Goodyear Aerospace Vee-Balloon (8000-Cubic-Foot Volume)	7
6	Natural Shape Logging Balloon	9
7	Wind Effect on a Tethered Balloon (Wingfoot Lighter-Than-Air Society Museum Collection)	9
8	Balloon Drag Coefficient at Zero Angle of Attack Versus Reynolds Number	10
9	Multilobe Internal Dilation Configuration	11
10	External Dilation Configuration	12
11	Internal Ballonet Configuration	13
12	Typical Balloon-Logging System	15
13	Tandem Balloon Schemes	16
14	General Arrangement of Tandem Balloons	17
15	Balloon With Internal Nose Girder and Surge Curtain	18
16	Fulton Skyhook Balloon - Personnel Rescue System, Sequence of Events	18
17	Effect of Intercept Altitude on Load Trajectory for Fulton Skyhook Balloon System	19
18	Goodyear Boomerang Balloon - Heavy-Load, Surface-to-Air Recovery System	20
19	Bedded-Down Natural Shape Balloon	21
20	Typical Balloon Manufacturer's Inquiry Sheet	24
21	Basic Weaves	33
22	Strength to Weight Comparisons - Film Cloth Versus Elastomer Laminates	39
23	Stress-Strain Curves for Nylon, Dacron, and Cotton Yarn	40
24	Specific Lift of Gases at Various Altitudes	48
25	Lift of Dry Helium Versus Temperature, Pressure, and Purity	52
26	Lift of Dry Hydrogen Versus Temperature, Pressure, and Purity	54
27	Specific Lift Versus Balloon Internal Temperature	55
28	Specific Lift Versus Altitude - Constant Balloon Temperature	55
29	Gross Lift Versus Diameter for Hot-Air Balloon	56

Figure		Page
30	Maximum Authorized Operating Limits for Raven S-50 Balloon	57
31	Hot-Air Balloon Envelope Dimpling Limits	57
32	Internal and Skin Temperature Profile of Hot-Air Balloon	58
33	Electrical-Driven Helium Compressor	60
34	Air-Dropped Inflation Gear Kit for 750 Cubic Foot Balloon	61
35	Hydrogen Processed by the Acid-Metal Process During the American Civil War	62
36	Hydrogen Generator Set AN/TMQ-3	64
37	Hydrogen Generator Set AN/TMQ-3 Inflation Equipment	65
38	Giffard's Captive Balloon (25,000 Cubic Meters) and Steam Windlass, 1878 (Charles Dollfus Collection)	69
39	AFCRL Balloon Tethering Site - WSMR, New Mexico	70
40	Types of Winch Installations	71
41	Basic Tethered Balloon Winch System Components	72
42	Largest Winch at Holloman AFB, 1968	72
43	Winch Storage Drum	74
44	Fleet Angle	76
45	Level Wind Mechanism	77
46	American Chain and Cable Co. Retrieving Winch	78
47	Fairlead	78
48	Tethered Site Layout for Winch Equipment	80
49	Smith-Berger Winch at Holloman AFB	81
50	Data Sheet for Capstan Type Winches	84
51	Glastran Elongation No. 1 for Various Diameters	94
52	Glastran Elongation No. 2 for Various Diameters	95
53	Elastic Elongation of Samson 2-in-1 Braided Rope	96
54	Strength-to-Diameter Ratios for Various Candidate Balloon Tether Materials	98
55	Strength-to-Weight Ratios for Various Candidate Balloon Tether Materials	99
56	Strength-to-Cost Ratios for Various Candidate Balloon Tethers	100
57	Balloon Tether Strand and Cable Data Sheet	101
58	Typical Cross Sections of Wire Rope Construction	103
59	Thimble End Fittings	106
60	Swaged End Fittings	107
61	Aerostrand-Monostrand Termination Requirements	108
62	Typical Potting Technique Used on Fiberglass Tethers	109
63	Typical Potted End Fitting Xray	109
64	Miscellaneous En ittings	110

Figure		Page
65	Brummel Hook Connection	111
66	Typical Bridle or Suspension Point	112
67	Balloon Handling Functional Breakdown	125
68	Installing and Erecting Balloon	126
69	Prelaunch Operations	127
70	Launch Operations	128
71	Balloon Flight Operations	129
72	Balloon Retrieval Operations	130
73	Balloon System Service and Maintenance Operations	131
74	Deflation and Pack-Up Operations	132
75	Effect of Superheat on Static Lift	149
76	Lift and Drag Coefficients Versus Angle of Attack for Various Balloon Configurations	153
77	Modern Helium Tractor Trailer (128, 230 Cubic Feet)	160
78	Helium Conservation Map	163
79	Locations of Possible Tethered Balloon Launch Sites	170

LIST OF TABLES

Table		Page
I	World War II Barrage Balloons - Single-Hull (Blimp) Shape, Hydrogen-inflated	25
II	Modern Tethered Balloons	26
III	Comparison of Basic Weaves	32
IV	Comparison of Filaments	34
V	Relative General Properties of Elastomers	36
VI	Comparison of Film-Cloth Laminates, Coated Fabrics, and Unsupported Films	38
VII	Available Coated Fabric Materials	42
VIII	Available Laminated Film-Fabric Materials	43
IX	Lift Ratios of Gases	48
X	Method of Calculating Balloon Size	50
XI	Available Winches	86
XII	Strength Efficiency Under Static Load	92
XIII	Comparison of Tether Materials	97
XIV	Elastic Conductor Specifications	104
XV	Knot Strength Comparison	105
XVI	American Chain and Cable Company Tethers	114
XVII	Columbian Rope Company Tethers	116
XVIII	Owens-Corning Fiberglas Corporation Tethers (Aerostrand)	117
XIX	Packard-Electric Tethers	117
XX	Samson Cordage Works Tethers	118
XXI	United States Plastic Tethers (Mylar)	119
XXII	United States Steel Tethers	120
XXIII	Temperature Sensors	135
XXIV	Pressure Transducers	136
XXV	Accelerometers	137
XXVI	Load Cells	138
XXVII	Wind Direction Transmitters	138
XXVIII	Wind Speed Transmitters	138
XXIX	List of Instrumentation Manufacturers	139
XXX	Water Vapor Pressure as a Function of Temperature	145
XXXI	Density Ratio and Unit Lift as a Function of Altitude (Helium - 95.5% Purity)	150
XXXII	Data on Helium Plants	164
XXXIII	Conversion Data for Helium	166

SYMBOLS

A	thickness of total layers of cable on drum (inches)
B	drum width between flanges (inches)
C	flange clearance (inches)
C_D	balloon drag coefficient $\left[C_D = \frac{2(\text{drag})}{\rho v^2 V^{2/3}}\right]$
C_L	balloon lift coefficient $\left[C_L = \frac{2(\text{lift})}{\rho v^2 V^{2/3}}\right]$
c_ℓ	unit gas lift (pounds/cubic foot) = $w_a - w_g$
D	drum diameter (inches); also envelope length (feet)
d	cable diameter (inches)
EMF	electro-motive force
F	line load (pounds)
f	cable coefficient of friction
FR	fineness ratio, $\frac{\text{envelope length}}{\text{envelope max dia}}$
FS	full scale; also factor of safety
K	constant as noted
L	tether length or envelope length (feet); also lift (pounds)
L/D	lift/drag ratio
n	number of units
P_T	tether load (pounds)
p	atmospheric pressure (inches Hg)
p_v	vapor pressure at 100% relative humidity (inches Hg)
q	dynamic pressure (pounds/square foot) $\left[q = \frac{1}{2}\rho v^2\right]$
S_g	specific gravity of gas
T	absolute temperature
T_a	ambient air temperature, absolute
T_b	average internal balloon temperature, absolute

V_K	speed (knots)
v	speed (feet/second)
v_{bal}	volume of ballonet (cubic feet)
$\forall$	envelope volume (cubic feet)
$\forall^{2/3}$	reference area (square feet)
$\forall^{1/3}$	envelope volume$^{1/3}$ (feet)
w	density of cable (pounds/cubic inch)
w_a	weight of air (pounds/cubic foot); in U.S. Standard atmosphere ρ is weight of air/cubic foot.
w_g	weight of gas (pounds/cubic foot)
α	angle of attack, degrees
θ	cable angle of contact with capstan; also gas purity
ρ	mass density of air (slugs/cubic foot); sometimes used as density (pounds/cubic foot)
ϕ	relative humidity

SECTION I

INTRODUCTION

1. GENERAL

Balloons are normally categorized to identify a particular balloon system, including the various trade names and models. Balloons are also identified by their shape, displacement, type of lifting gas used, and the operational use of the balloon and its associated tethering cable. Most balloons can be scaled up or down in size, built of material of greater or lesser strength (and weight), and in numerous ways optimized for a specific application. Basic criteria for balloon design include altitude requirements, total payload to be supported, including tether of adequate strength, and flight loads to be endured.

2. TETHERED BALLOON HISTORY

Modern tethered balloons are flown unmanned except in a few isolated operations. The first manned flight was made in a tethered balloon on October 15, 1783, at Paris, by Pilatre de Rozier. On October 17 Rozier made another ascent, accompanied by Gironde de Villette, who immediately suggested the possible military advantages of the elevated position provided by the balloon in a letter written to the editors of the Journal de Paris on October 20, 1783, and published on October 26.

In 1793 Gaspard Monge proposed to the Convention governing France after the fall of Louis XVI the use of captive balloons in the war to repel the armies invading France. The suggestion was adopted, and an act ordering construction of a military balloon was passed on October 25, 1793. A balloon school was founded at Mendon, and a balloon corps consisting of two companies was organized. By 1795 four balloons had been built. One of these, the Martial, was a cylindrical balloon, but was more unsteady in a wind than the spherical types, presumably because it lacked stabilizing fins. Pictures of these early tethered balloons show that twin tethers were used (see Figure 1). The twin tethers were most likely used to combat the inherent instability of spherical balloons, which develop a lateral oscillation across the wind field at a relatively low wind velocity.

The Aerostiers, as the members of the corps were called, operated with some success, but the corps was ordered disbanded in 1799, apparently because balloons were unsuited to the mobile tactics of Napoleon, being better suited for use in static warfare such as sieges. (However, a company that accompanied Napoleon to Egypt in 1798 was not disbanded until its return to France in 1801 or 1802.)

There was little military ballooning activity thereafter until the outbreak of the American Civil War in 1861, although suggestions were made in the U. S. by Col. J. H. Sherburne in 1840 that they be used in Florida against the Seminole Indians, and by John Wise in 1846 during the Mexican War that a tethered balloon be used to bomb Vera Cruz (Reference 1). Margat took a French balloon to Algeria in 1830 and made one ascent under fire, and in 1859 Louis and Eugene Godard used captive hot-air balloons during the French campaign in Italy.

Captive balloons were used by both sides in the American Civil War. On the Union side, after some mixed successes, a balloon corps of seven balloons with field generators for hydrogen was organized under Thaddeus Lowe (see Figure 2). Lowe resigned in 1863 because of a salary cut and because of unrealistic hampering restrictions put on his operations. The balloon corps tried to continue under James Allen but disbanded not long afterward. The first shipboard use of a tethered balloon was by John La Mountain on August 3, 1861, and Lowe soon followed with an ascent from the first boat built for balloon operations, the G. W. Parke Custis, in November 1861.

The Confederates, with considerable ingenuity, gained mobility for one of their balloons by tying it to a locomotive and later to a steamboat on the James River.

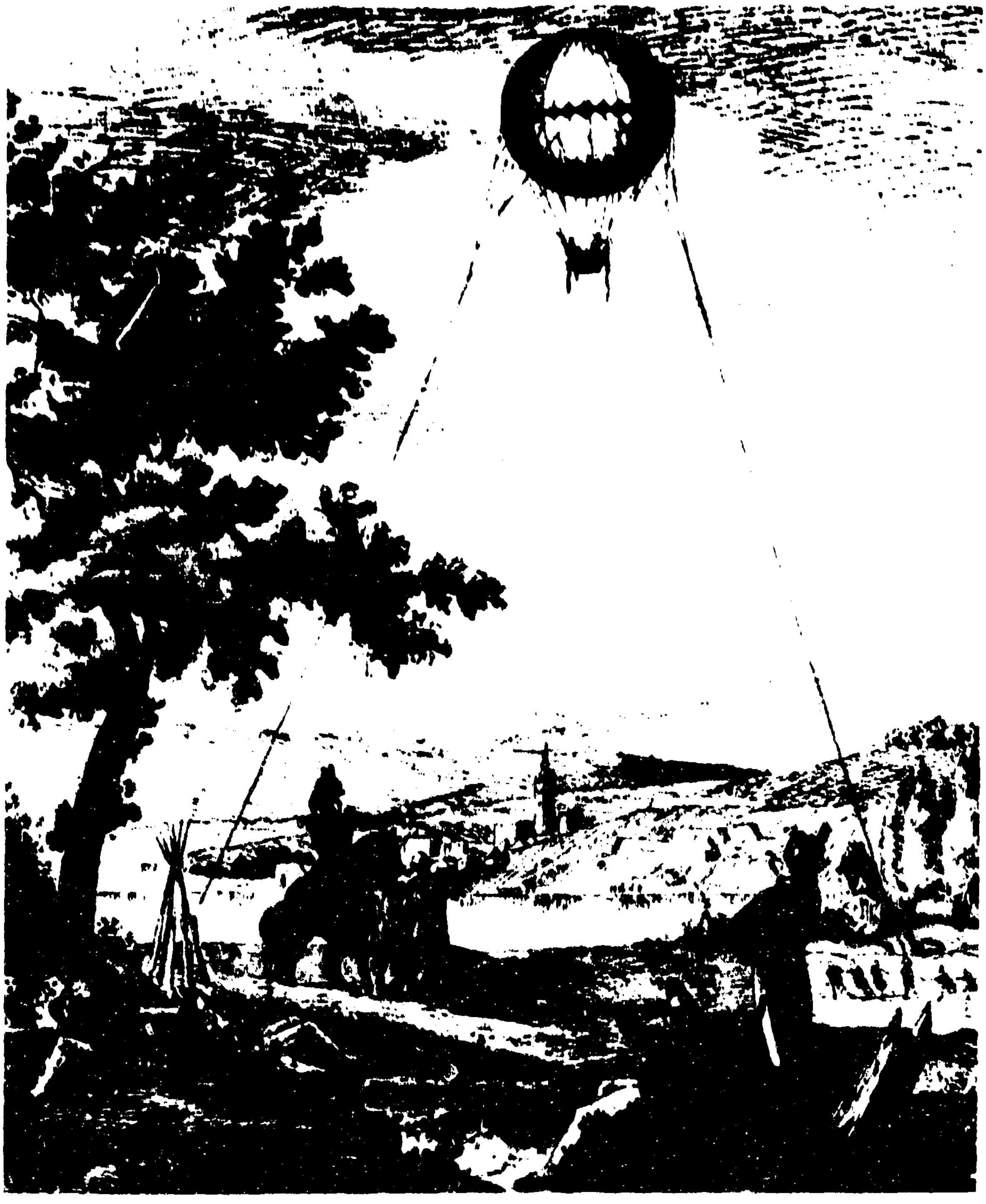


Figure 1. Double Tethered Balloon, Early French, 1795

Figure 2. Lowe's Balloon Washington Aboard the Custis During American Civil War, 1861 (Smithsonian Institution)

Captive balloons were used rather ineffectually by both sides in the Franco-Prussian War of 1870. In 1879 the British army adopted captive balloons, and in 1880 introduced the storage of gas in steel cylinders for transport. During the 1880's, most of the countries of Europe organized balloon divisions, some of which saw action in colonial wars.

The German army's balloon division was responsible for the first great technical advancement in captive balloons since the Aerostiers were disbanded (Reference 2). The greatest difficulty with captive spherical balloons, once official disinterest and inertia were overcome, was that even a light wind caused them to "oscillate, bounce, and twist in a manner too violent for the strongest of stomachs to stand" (Reference 2). The Germans tried an elongated balloon (called Cigarre) with no more success than the French had had 100 years before. In 1892, however, Parseval, Sigsfeld, and Riedinger designed the first kite balloon, or "drachen," which made use of the wind for stability as a kite does (see Figure 3). The rigging of the balloon was such that the cylindrical envelope flew at about a 45-degree attitude. A single, thick, air-inflated lower vertical tail fin served as a ballonet. It was not immediately successful, but after various improvements, including a tail of drogue cups to produce a stabilizing drag force, a sufficiently satisfactory design was attained by 1896 that the War Ministry ordered several. Conservative members of the German balloon corps argued that the spherical balloons could go higher and were therefore superior. However, experience demonstrated that the drachens could ascend in weather that kept the sphericals grounded a third of the time and they could reach an altitude sufficient for satisfactory results. Thus kite balloons replaced spherical balloons in the German army.

A kite balloon tapered to points at both ends was suggested by Captain Tokunago of the Japanese army in 1899 (Reference 3). Model tests showed good results, and a full-scale balloon was built in Japan; but by 1905 the Parseval-Sigsfeld kite balloon had been introduced there.

Although Russia, Sweden, Italy, France, Austria, Spain, Japan, and the United States had all experimented with kite balloons, at the outbreak of World War I only the Germans seemed to have been using them; and captive balloons, because of their lack of mobility, were not regarded even by the Germans as likely to be very useful as Germany anticipated a "blitzkrieg" war. The German generals favored the military philosophy of the headlong offensive, believing that since it didn't matter what the enemy did anyway, scouting was unnecessary. When the fighting settled into trench warfare, however, the captive balloon became suddenly important. The French and British, who were still using spherical balloons, soon recognized the superiority of the drachen and copied the design. In 1915, a French army captain, Caquot, designed a better captive balloon using three inflated fins to improve stability. Before the war was over, the Germans had copied and were using Caquot's design.

Balloons were also tethered to surface ships (see Figures 3 and 4) and used for scouting and submarine spotting by the allied navies; ships were especially constructed with balloon wells for handling the balloons. Incidentally, it was the vulnerability of the hydrogen-filled observation balloons of World War I to incendiary fire that led to development of helium production in the United States.

Between World Wars I and II, the principal captive balloon development was the addition of a motor and suitable controls to the kite balloon so that it could be flown from one station to another, thus improving its mobility. These motorized kite balloons were used at the beginning of World War II by both Germany and France, but did not play an important role.

The purpose of all military ballooning was to elevate a human observer to a point from which he could see the enemy's activity. With the development of the bombing airplane, a new problem arose and the balloon barrage was developed as a defense. A forest of these balloons tethered by steel cables over a city made low-level bombing difficult, if not suicidal. Developed late in World War I, they were used in large numbers during World War II around London and other cities. They were also employed to protect surface ships, notably Eisenhower's D-Day invasion fleet. Several designs were developed, but the two principal types were (1) the ballonet type (like the drachen and the Caquot balloons with three fins) and (2) the dilatable-gore

Figure 3. German Drachen Towed by Torpedo Boat (Smithsonian Institution)

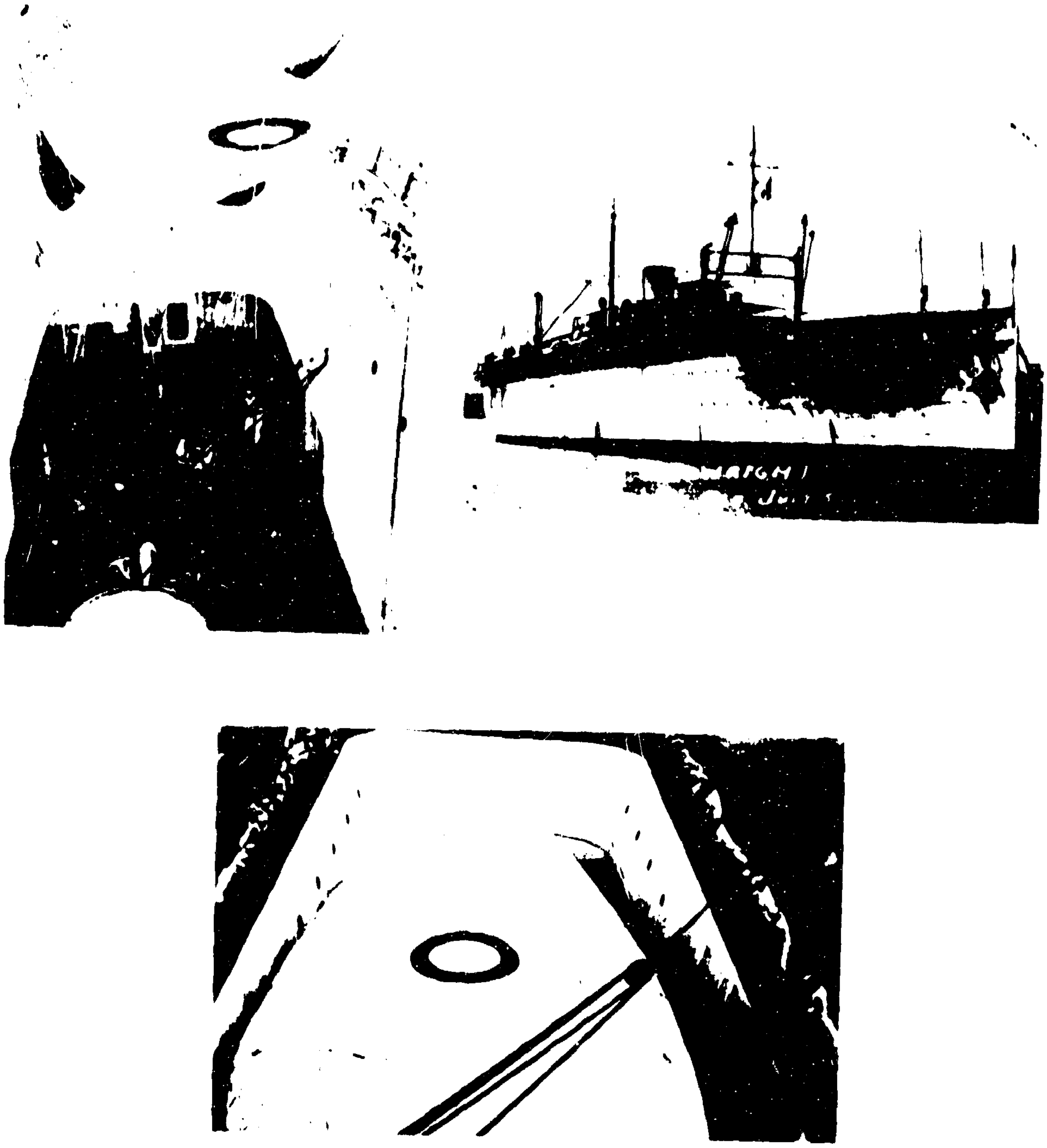


Figure 4. Handling a Balloon Aboard Navy Ship (Wingfoot Lighter-Than-Air Society Museum Collection)

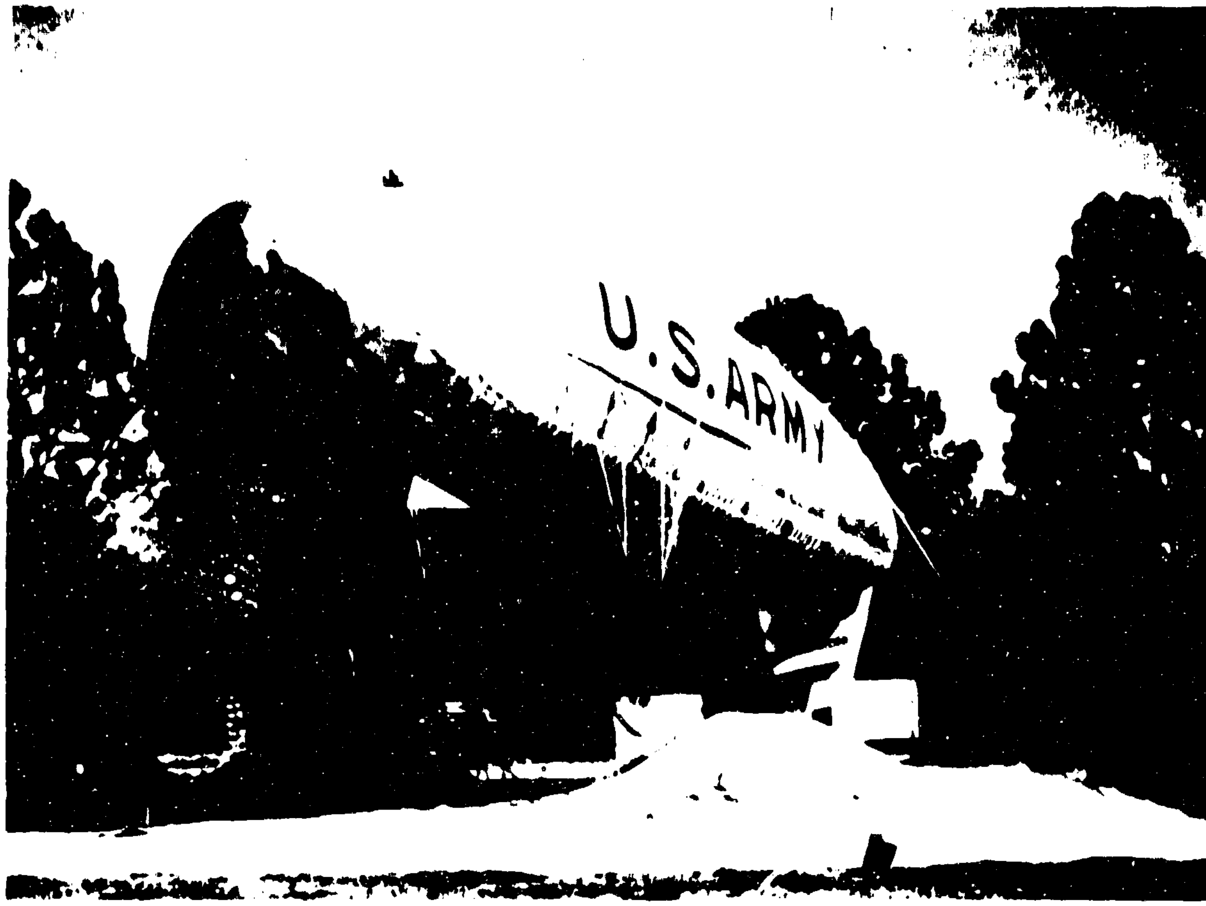


Figure 5. Goodyear Aerospace Vee-Balloon[1]
(8000-Cubic-Foot Volume)

type with from four to six or eight fins. Barrage balloons have been used more recently in the defense of Hanoi in North Vietnam.

In the 1960's, new unmanned applications for tethered balloons came into being, with antennas or instrument packages replacing the human observer of earlier times. A recent application is the support of low-frequency antennas for military communications. Another is the use of balloons as a marker and cable support in several aerial pickup and rescue systems in which an airplane flying by snatches the cable and reels in the payload by means of an onboard winch and grapnel system. Balloons are also used in the logging industry in areas inaccessible by conventional logging methods. The French used a captive balloon to suspend a nuclear bomb during a test in the South Pacific. Balloons have been used in lieu of tall towers to support various electronic payloads.

In logging operations and in some proposed very high altitude tethered systems, two or more balloons in tandem (one above the other) may be used. This consideration led to a configuration that is called the Vee-Balloon, a twin-hulled design with a horizontal fin closing the V (see Figure 5). The cable to the balloon or balloons above (in a tandem arrangement) runs

[1]T. M., Goodyear Aerospace Corporation, Akron, Ohio 44315

through the crotch. Incidental advantages of this configuration are (1) much greater aerodynamic lift, which is especially useful in logging, and (2) greater stability than conventional single-hull kite balloons.

This review has traced primarily the history of military ballooning. Nonmilitary uses of tethered balloons have not been as well recorded. They have existed as toys since September, 1783, and tethered balloons have ascended with people aboard ever since Pilatre de Rozier's day (Reference 4). In 1868, Henri Giffard in London built a captive balloon that was 370,000 cubic feet in volume and capable of lifting 28 people. The following year Giffard built a 425,000 cubic foot balloon. These were tethered to a steam winch that raised and lowered them. Giffard built what was surely the largest captive balloon ever for the Paris World's Fair in 1878. It was 880,000 cubic feet in volume and lifted 50 people at a time, operated by a huge steam winch. This balloon and winch are illustrated in Figure 38 (Section V).

The most common nonmilitary use of the tethered balloon has been for advertising. Demand in this area has led beyond small kite balloons to balloons shaped and painted to simulate wine bottles, light bulbs, stockinged legs, and even an automobile battery. These are variations of the figure balloon, which dates back to 1785, when the Entslen brothers of Strasbourg built from goldbeater's skin a hydrogen-filled balloon shaped and painted like the winged horse Pegasus. Perhaps the best-known examples of figure balloons in modern times are the balloons in Macy's annual Thanksgiving Day parade in New York City.

Another use of tethered balloons is to support aerial cameras. The idea has been used in recent years for various kinds of aerial surveys (archaeological investigations, for instance).

Tethered hot air balloons have been used at sea from shipboard by the U. S. Bureau of Commercial Fisheries, La Jolla, California, in experiments involving fish spotting. Jacques Cousteau has used a Raven hot-air balloon in similar fashion with his research vessel in various underwater researches.

3. SHAPES AND STABILITY

The shapes of balloons are normally divided into the three categories listed below.

(1) Spherical

(2) Natural Shape

(3) Aerodynamic Shape
- (a) Single Hull (blimp)
- (b) Vee-Balloon (double, intersecting hulls)
- (c) Other

The first two categories are the earliest shapes, and are logical as promising the greatest volumetric efficiency. The natural shape is more efficient from a structural standpoint whenever the payload is a finite concentrated load to be supported by the balloon (see Figure 6). Both of these shapes are widely used for free balloons, but are limited in tethered applications. As free balloons, they feel no wind after launch, except for casual gust effects. The natural shape free balloon is normally vented by an appendix and has no pressurization other than the head of lifting gas in the envelope.

When tethered, any balloon - regardless of configuration - will have an externally applied pressure on the windward side. The balloon is thus subject to dimpling or "cupping" if it does not have a greater internal pressure than the externally applied dynamic stagnation pressure (see Figure 7). The wind speed for initial dimpling of a given configuration does not represent an absolute upper limit for flight, but it is the onset of both structural and flight instability.

Photo supplied by Raven Industries, Inc.

Figure 6. Natural Shape Logging Balloon

Figure 7. Wind Effect on a Tethered Balloon
(Wingfoot Lighter-Than-Air Society
Museum Collection)

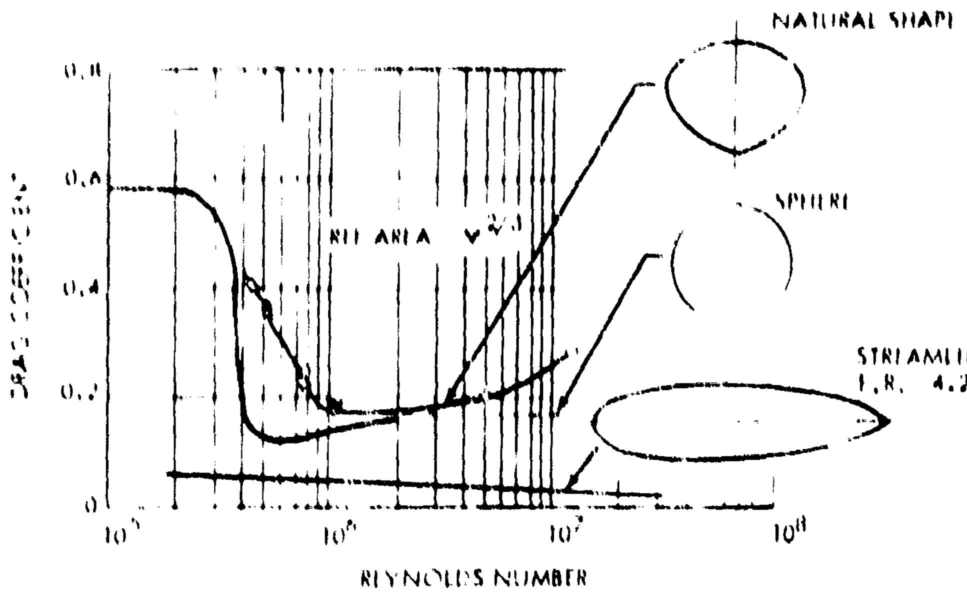


Figure 8. Balloon Drag Coefficient at Zero Angle of Attack Versus Reynolds Number

Even before the dimpling limit is reached, the spherical or natural shape balloon normally exhibits the lowest tolerance for wind - approximately 10 to 15 knots due to blowdown and lateral oscillatory movement across the direction of the wind field. (Blowdown is defined here as the downwind excursion from the tethering point.) A natural shape balloon will have the greatest drag in wind, a spherical balloon of the same volume a somewhat lesser drag, and an aerodynamically shaped balloon the least drag (see Figure 8). Aerodynamically shaped balloons were, initially, a response to the high drag and instability of the early spherical balloons and their resultant wind limitations. Blowdown is reduced by increasing the lift-to-drag ratio (L/D). The lift is total lift, both static and dynamic; the drag of course, is dynamic. For minimum blowdown, high L/D is desired, and the total lift would desirably be primarily static. In a special application such as logging, high dynamic lift may be desired even at the expense of high drag.

4. PRESSURE SYSTEMS

The aerodynamically shaped balloons are operated in winds as high as 50 or 60 knots. A superpressure is required to prevent nose cupping and can be provided by either a dilation system or a ballonet system.

A dilation system is an internal or external bungee cord arrangement which, either through a change in balloon cross-sectional geometry or an expansion of a gore or several gores, permits a change in the volume of the balloon with changes in altitude and temperature. The change in volume is normally indicated by a gauge band. Internal and external dilation configurations are shown in Figures 9 and 10, respectively. The balloon must have a minimum pressure at launch, provided by topping with lifting gas, and internal pressure will increase to the limits of the dilation system with an increase in altitude or temperature. The envelope is ordinarily protected by a "pop-off" relief valve. Minimum pressure must be great enough to prevent "dimpling" and buckling due to winds.

The ballonet system (see Figure 11) consists of a curtained-off space within the fixed-volume envelope in which ambient air is pumped under slight superpressure. Expansion of the

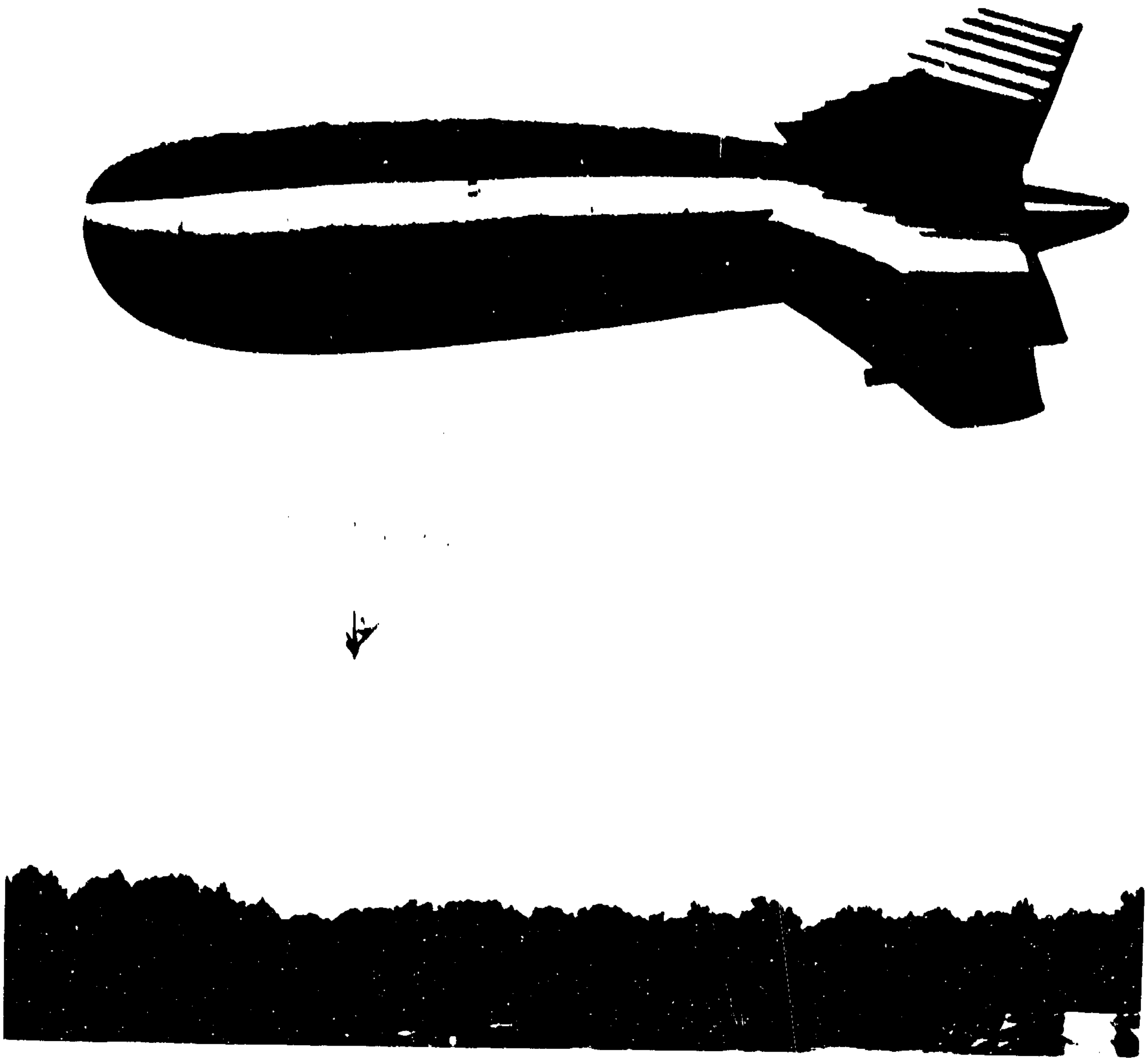


Photo supplied by Th· Goodyear Tire & Rubber Co.

Figure 9. Multilobe Internal Dilation Configuration

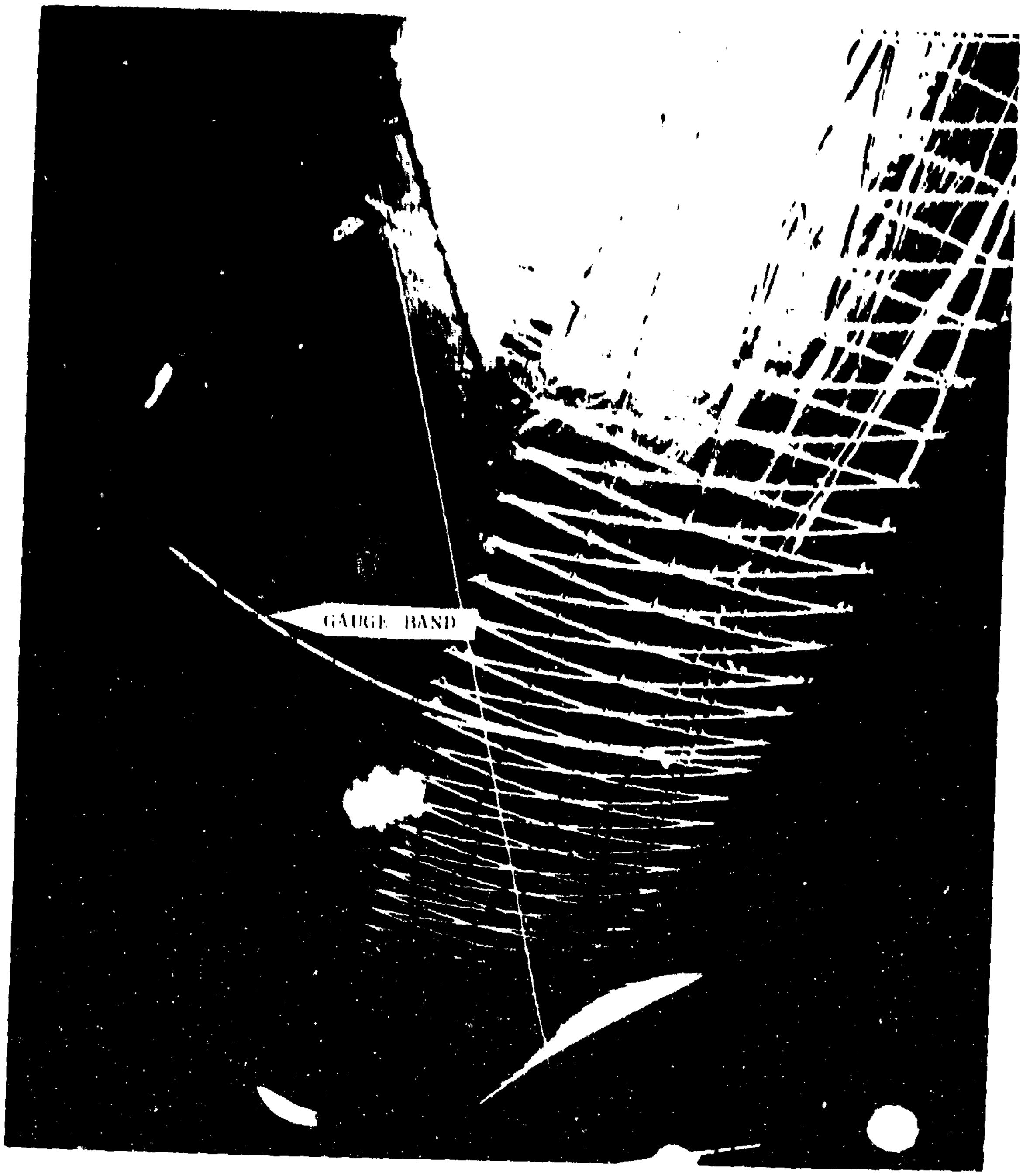


Figure 10. External Dilation Configuration

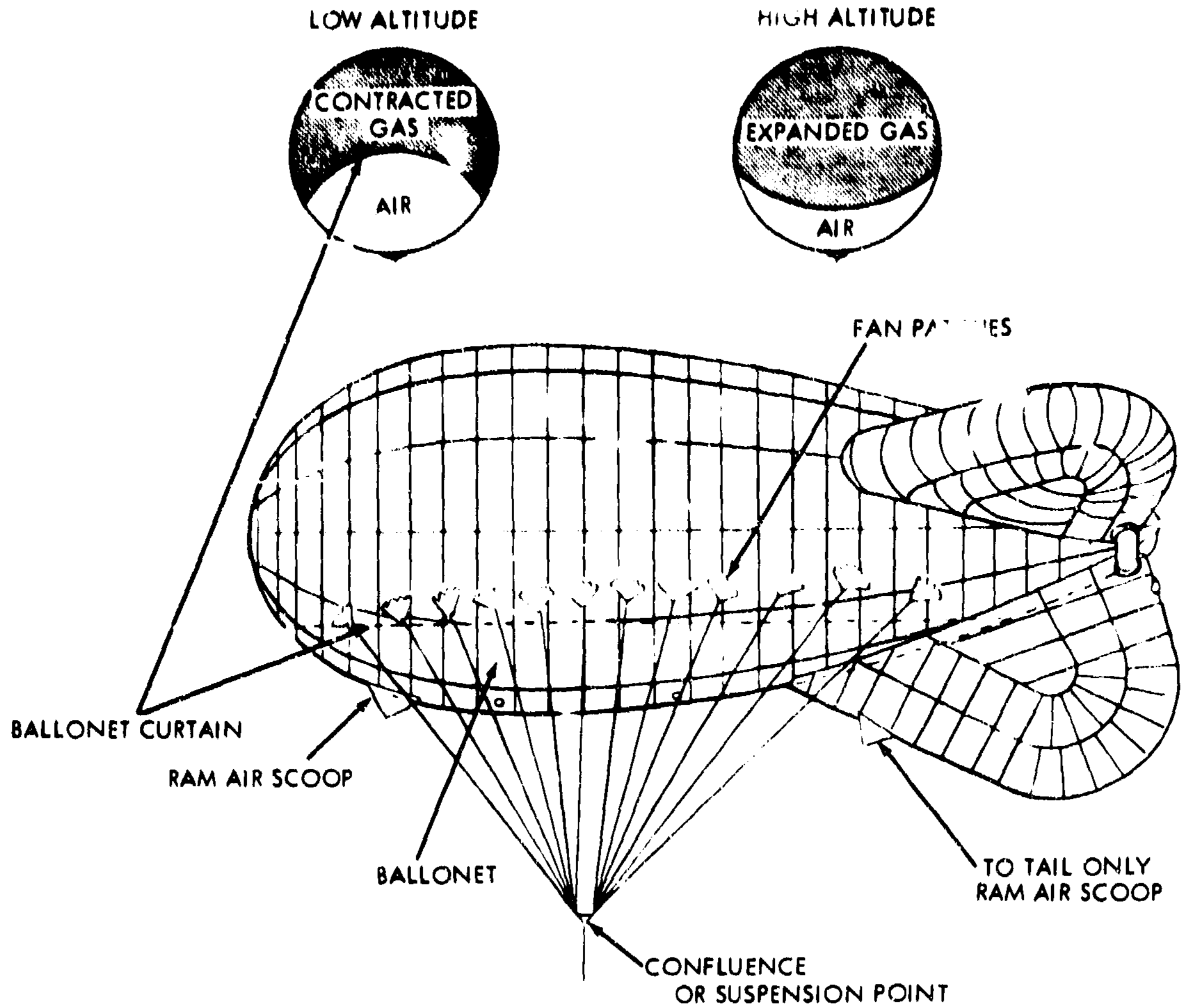


Figure 11. Internal Ballonet Configuration

lifting gas due to altitude or temperature change is permitted at the expense of ballonet volume. Pressure height is, by definition, the altitude at which the envelope is 100 percent full of lifting gas and the ballonets empty, and depends upon takeoff inflation. An envelope relief valve is normally incorporated to protect the envelope by valving gas when pressure builds up after pressure height is exceeded or higher temperatures develop.

The ballonets are inflated and pressurized either passively by strategically located ram air scoops or by a windmill-driven blower, or actively by a pressure-switch controlled, electrically-powered blower. Power may be supplied by battery or from the ground by wires routed with the tether. Back-flow valves or collapsible sleeves prevent loss of air through scoops or blower during no-wind or blower-off condition. Inflated empennages may be either air- or gas-inflated. Lower fins have frequently been air-inflated because of vulnerability to ground damage and greater ease of deliberate deflation without loss of gas when bedding down.

Both dilation systems and ballonet systems are directly influenced by the altitude excursion and superheat requirements of a given balloon specification. Dilation systems are simpler, passive, generally heavier, and ordinarily used for lesser altitude excursions. Ballonet systems are more complex, usually active (electrical blower), capable of maintaining a

predetermined pressure, and provide a constant balloon configuration. The dilation bungee cord is subject to deterioration from weathering, and dilation gores are normally located on the underside of the envelope to provide protection from sunlight and avoid water entrapment. Changes in balloon volume and geometry must be considered in suspension and confluence point design as well as in empennage arrangement and bracing. The pressure system essentially lets the balloon "breathe," that is, change volume without loss of gas to compensate for altitude change, temperature change, etc. Usually for short flights with small changes in altitude (less than 500 feet), the pressure system can be eliminated since the air density change is small.

Aerodynamically shaped balloons are inherently heavier for a given volume than spherical or natural shape balloons, but they are capable of operation in higher wind velocities. Because of their higher wind operational capabilities, tethering requirements will tend to stronger - and heavier - cables. As always, the precise choice of balloon configuration and its detail design are primarily functions of the operating specifications the balloon is to fulfill.

5. BALLOON SYSTEM OPERATIONAL REQUIREMENTS

Operation and performance requirements for a particular balloon system dictate the selection of materials and the design configuration. For example, a long service life with numerous launch and retrieval cycles and handling operations or the capability of withstanding high wind, long-duration flights, and long exposure to the elements may require a heavy rugged material. On the other hand, a short service life, short flights, very high lift or high altitude may permit or dictate a lightweight, less-rugged material. Operational and performance requirements, such as environmental conditions, type and frequency of ground handling operations, service life, flight endurance, lift, altitude, number of launch and retrieve cycles, number of inflation and deflations and packaging, are all interrelated factors that require careful consideration to provide an optimum balloon system for a particular application.

6. SELECTING A BALLOON SYSTEM

Normally a tethered balloon system can be selected by one of three approaches: (1) punch a system out of a table (refer to Tables I and II in Section II), (2) start with an available balloon and build up a balloon system around that available balloon, or (3) start with a required payload and an operational requirement. In any system selection, after the system operational requirements are known, the balloon configuration and type of lifting gas must be considered to suit the stability and safety requirements. Then the size of the envelope must be selected (refer to Table X), based on the type of gas used, the envelope weight, and the total tether weight at maximum operating altitude. The envelope material selected (refer to Section III) is governed by the maximum load requirements expected under heavy wind conditions and the envelope internal operating pressure, plus a safety factor. When men are raised aloft in the balloon, the safety factor is normally increased. The tether cable (refer to Section V) must be selected for the specific job, taking into account length, electrical load where applicable, diameter, strength, and a safety factor. In the selection of winches (refer to Section V), the following must be considered: length and diameter of tether cable, the method by which the winch is secured or ballasted to base, rate of reel-in and reel-out of tether, type of power source, type of brake used, size of fairlead, type of drive coupling, type of controls, safety of operator, and often the various instruments used in conjunction with the winch and tether.

SECTION II

BALLOON SYSTEMS

1. GENERAL

The history of tethered balloons has indicated their early military exploitation for observation and reconnaissance, and later as balloon barrages to obstruct heavier-than-air craft. Their present development and use are primarily for the elevation and support of men, instruments, communications gear, etc.

Logging of otherwise inaccessible terrain has been under development since World War II. Both dynamic-lift and all static-lift types of balloons have been used in this very rugged application (see Figure 12). Such balloons are heavily loaded, low-altitude types handled by specialized winches or logging yarders in an overall logging system.

At the other extreme is a 112 cubic foot, 1/4-mil Mylar bilaminate kite-balloon made by E. Bollay and Associates. This delicate system can lift a 2-pound, 5-ounce electronic payload to 5000 feet for a specific short-life atmospheric research operation.

Attempts to reach higher altitudes by the use of balloons in tandem (two or more stacked vertically) have been made since at least 1918. Recent studies of feasibility of tethering to as high as 100, 000 feet have shown this technique as not only desirable, but absolutely necessary.

Figure 13A illustrates the earliest tandem arrangement attempted, in about 1918. Figure 13B is a later, through-the-envelope, tethering arrangement. Greater detail is shown in Figure 14. Figure 13C avoids the through-the-envelope arrangement with a tethering through

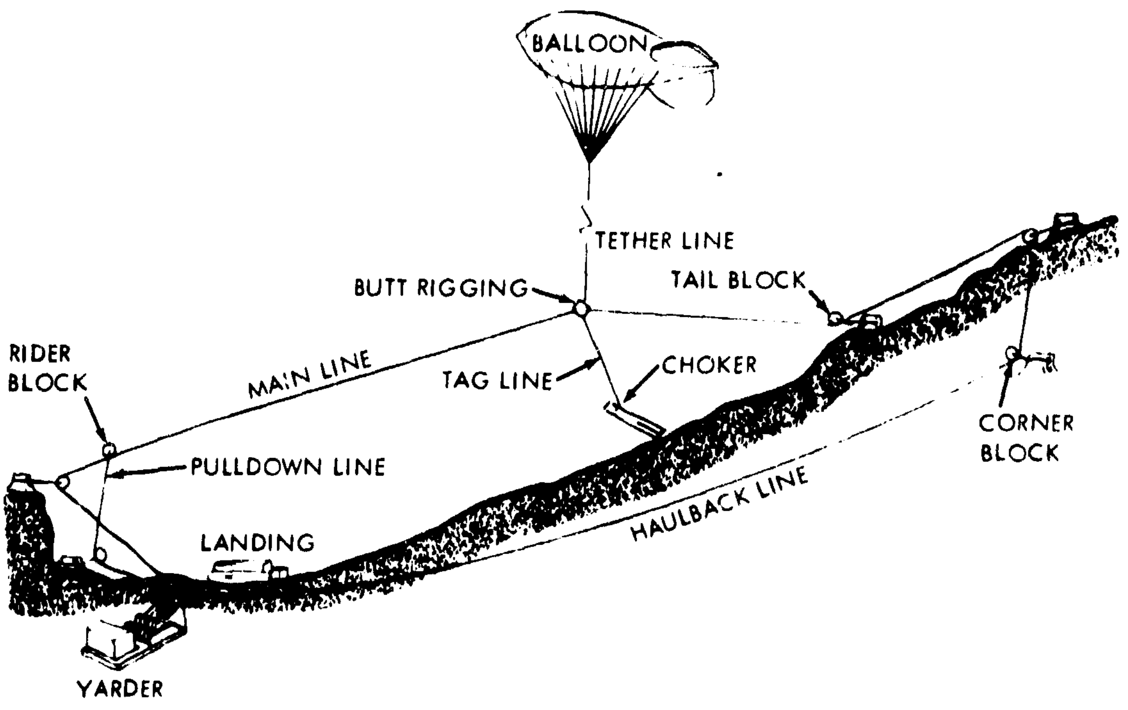


Figure 12. Typical Balloon-Logging System

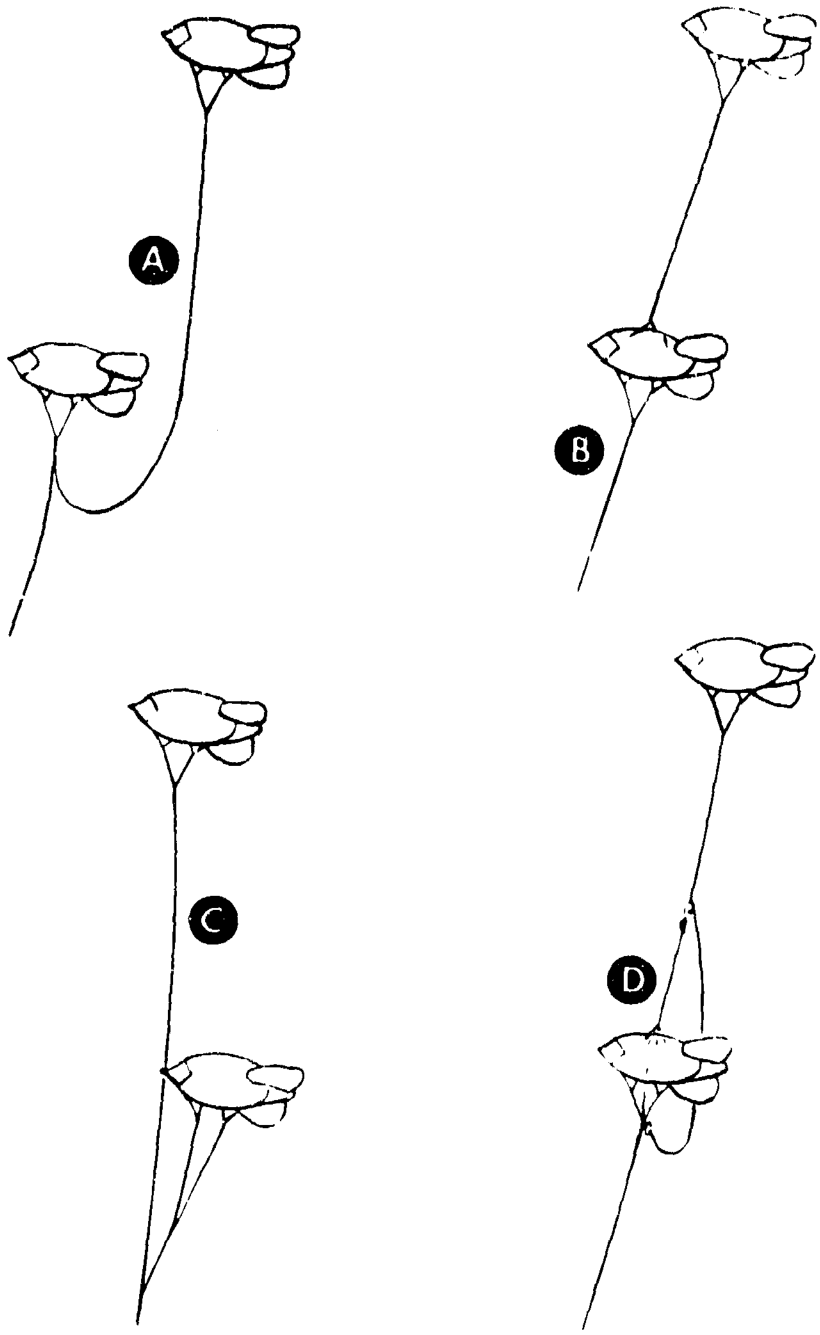


Figure 13. Tandem Balloon Schemes

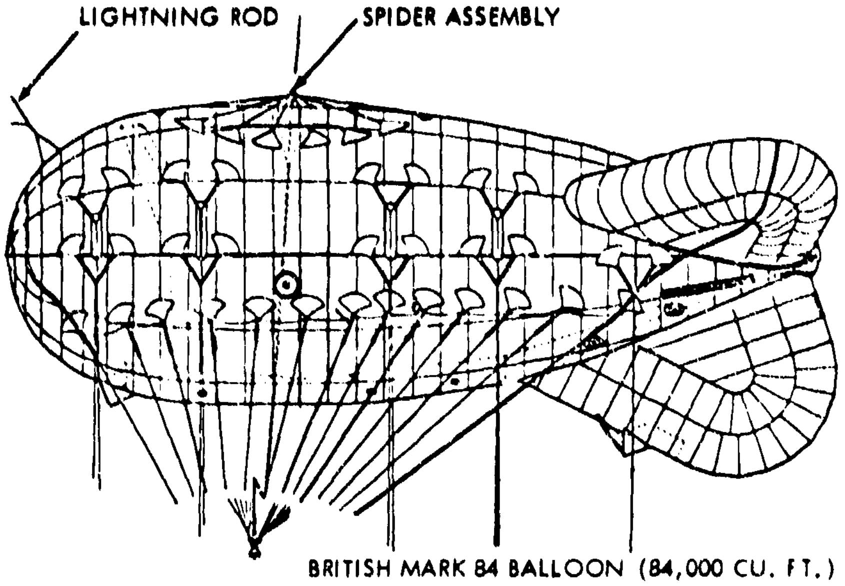


Figure 14. General Arrangement of Tandem Balloons

a nose spike or cone arrangement. Figure 13D is essentially similar to Figure 13B, but provides easier recovery of the upper balloon with the addition of an auxiliary line and disconnect fitting.

One of the advantages of Vee-Balloons in tandem is the capability of tethering the upper balloon through the crotch area of the lower balloon, avoiding any necessity of penetrating the gas-filled envelope.

High-altitude balloons of the ballonet type have been destroyed by surging of the gas-air combination at low altitude. A severe shift of center of buoyancy can cause buckling from the abnormal loadings on the suspension. Figure 15 illustrates a balloon with a surge curtain, which inhibits or damps surging of the gas-air combination. The curtain is porous, but provides resistance to a sudden gas shift.

Modern recovery or rescue systems involving tethered balloons include the Fulton Skyhook system for personnel rescue and the Goodyear Boomerang for a heavy payload recovery. Both involve balloons for elevating a high-strength tether from 400 to 500 feet above the terrain. A recovery aircraft with onboard winch strikes the line or the balloon, snatches the payload into the air, and winches the payload into the aircraft while in tow. Maximum g-forces on the payload are from 5 to 7 g's with nylon tethers and 120-knot aircraft impact speed. Figures 16 and 17 show some of the particulars of the Fulton rescue system. Figure 18 shows Goodyear's Boomerang heavy payload recovery system.

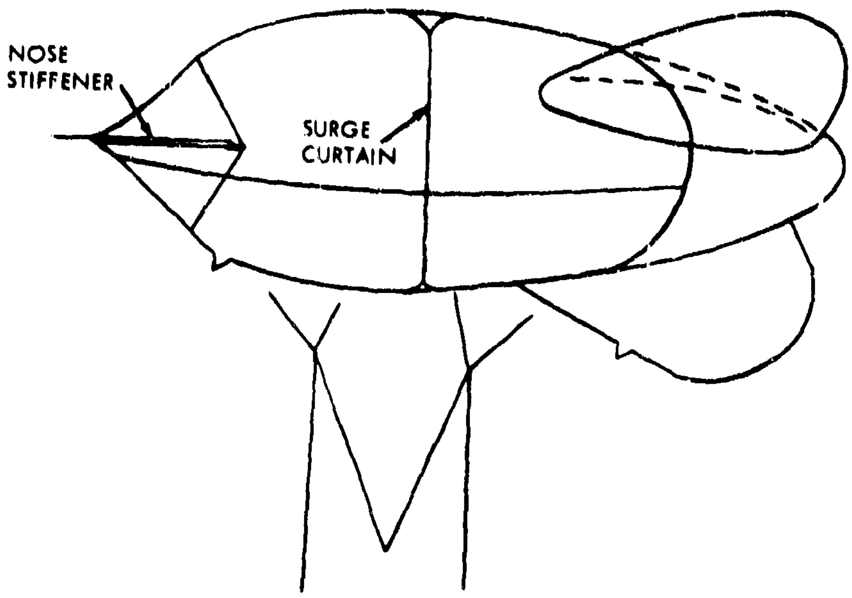


Figure 15. Balloon With Internal Nose Girder and Surge Curtain

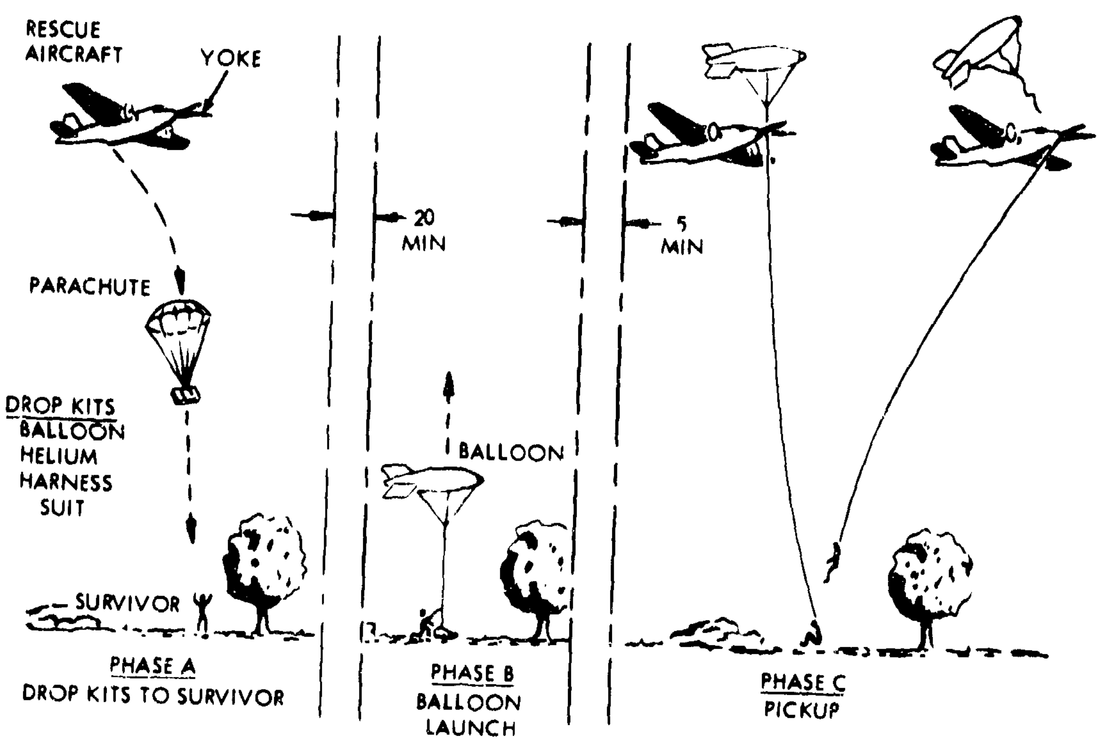


Figure 16. Fulton Skyhook Balloon - Personnel Rescue System, Sequence of Events

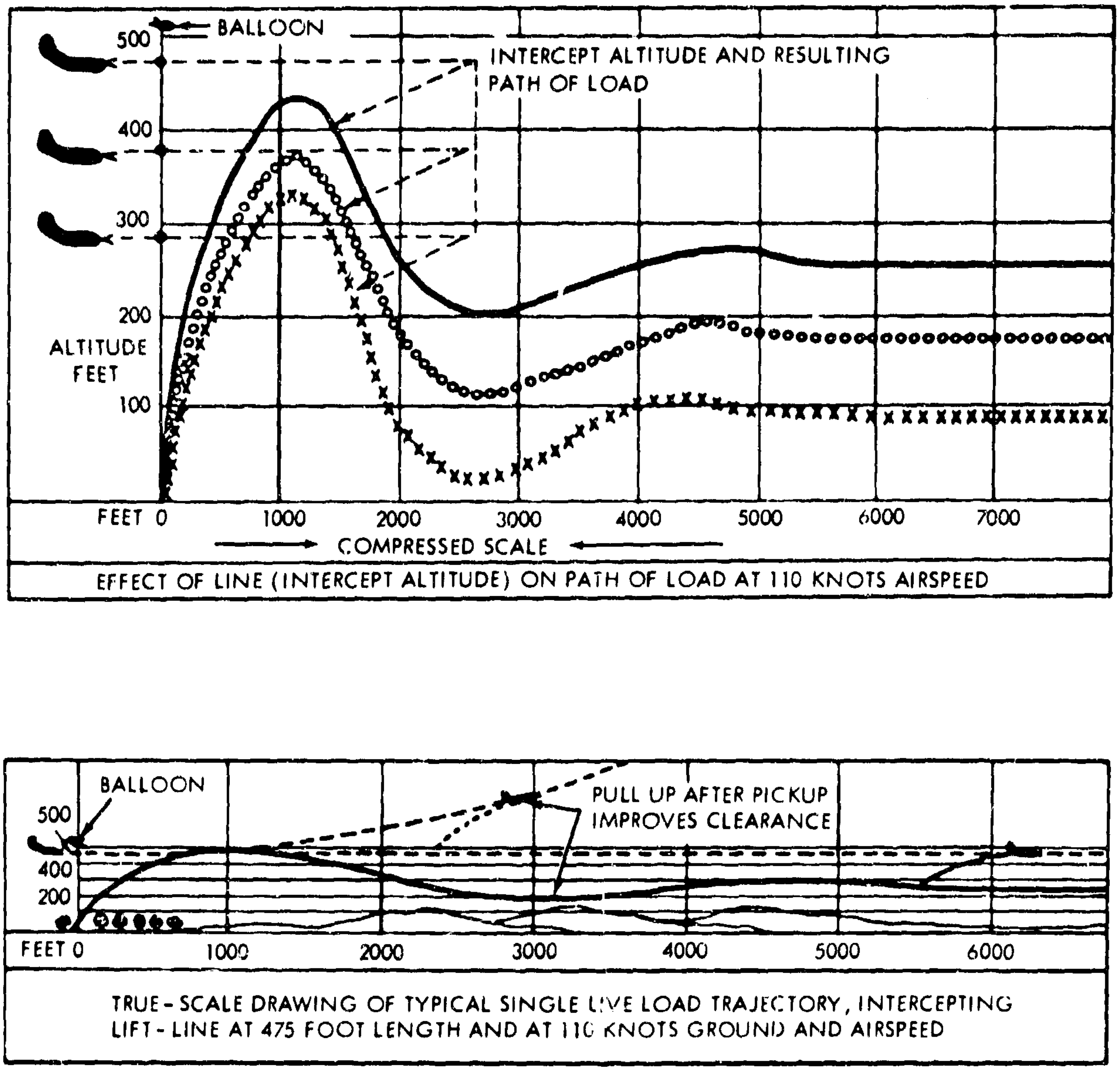


Figure 17. Effect of Intercept Altitude on Load Trajectory for Fulton Skyhook Balloon System

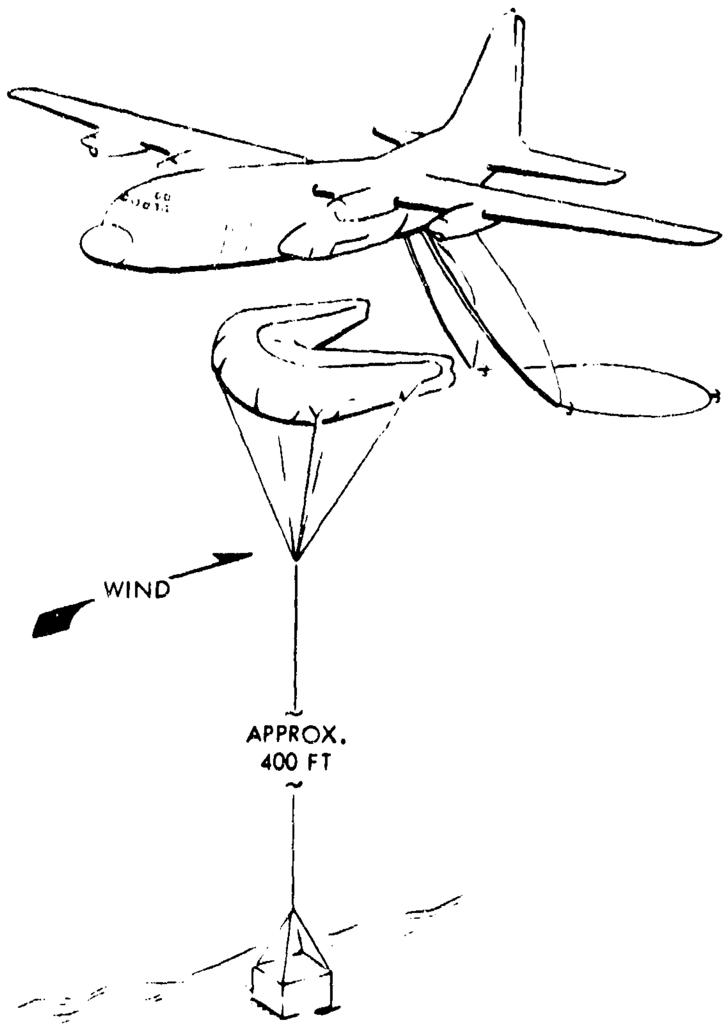


Figure 18. Goodyear Boomerang Balloon - Heavy-Load, Surface-to-Air Recovery System

2. HELIUM-FILLED BALLOON SYSTEM

All tethered balloon systems, regardless of type of lifting gas used, have many common elements. The "flying" part of the system consists of the inflated balloon, its empennage, over-pressure valve, ballonet or dilation system, destruct system, suspension, tether line, and ground winch.

"Bedding-down" between flights requires a smooth, clear ground area, ground cloth, permanent or temporary ground anchors, and handling lines or tie-down patches on the balloon itself. A bedded-down balloon is shown in Figure 19.

Inflation or erection of a balloon, if in the open, requires an area similar to or identical with the bedding-down area. During inflation, the balloon may be controlled and restrained by balloon handling lines or by a netting over the envelope. If netting is used, a supply of 25 to 50 pound sandbags or shot-bags with short ropes and S-hooks are hooked into the netting on either

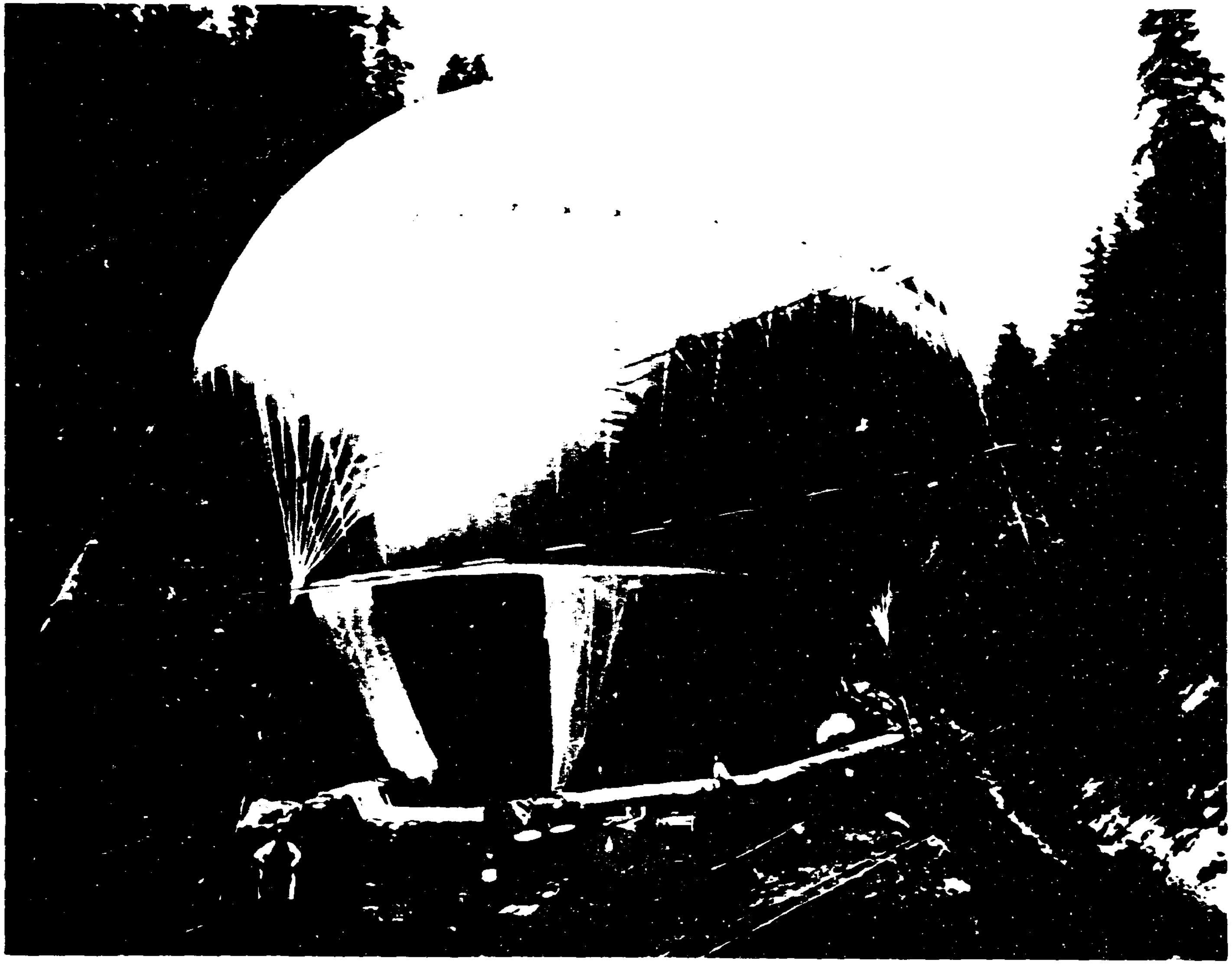


Photo supplied by Raven Industries, Inc.

Figure 19. Bedded-Down Natural Shape Balloon

side of the envelope. As inflation proceeds, the bags are hooked progressively lower in the netting, permitting the envelope to rise until finally it can be handled by handling lines and tether. The shot-bags and netting can then be removed.

In the case of a helium-filled balloon, the helium is available only from storage in containers at high or low pressure. "Nurse" bags have been used, storing helium at atmospheric pressure, usually after removal from a balloon envelope. Normally, the gas will be available from gas cylinders at 1800 psig. Elaborate installations may have underground or aboveground storage of helium (refer to Appendix II). A balloon is inflated by connection of a helium line to an appropriate fitting or sleeve on the balloon. With any gas under pressure, there will be a refrigeration effect from the gas expansion to atmospheric pressure. In a large or permanent operation, helium purification apparatus may be a part of the ground equipment for maintaining balloon helium at acceptable purities.

3. HYDROGEN-FILLED BALLOON SYSTEM

The primary differences between helium-filled and hydrogen-filled balloon systems are in the attention to details of design and the techniques of inflation and handling to prevent ignition of the explosively flammable hydrogen. A balloon designed for use of hydrogen can certainly be used with helium, with about an 8 percent loss in gross lift.

The serious hazard of a hydrogen-air mixture is due to the wide range of combustion limits: 4 to 74 percent by volume in air is flammable.

Detail design of the balloon includes electrical bonding of metal parts of over-pressure valves, which otherwise might be electrically separate. Any electrical equipment to be carried by the balloon or in the vicinity of an inflation (switches, relays, motors, etc) should be explosion-proof or kept remote. A "unicorn" nose probe, grounding down the tether to earth, has been used to dissipate ambient electrical potentials when flying (see Figure 14).

Hydrogen is available in high-pressure cylinders or by means of a number of chemical processes. The chemical generators usually require a source of local water.

4. OTHER GAS-FILLED BALLOON SYSTEMS

The only other lifting gases occasionally used are coal gas and ammonia. Because of their greater weight, a balloon inflated with these gases has a much reduced lift compared with that of helium or hydrogen.

Both coal gas and ammonia are flammable, but not with the wide limits of hydrogen. The balloon system suitable for hydrogen will certainly suffice with these two gases, always considering the vastly lessened lifting capability.

Ammonia vapor is highly irritating to eyes and nasal membranes. Any appreciable concentration will be objectionable to personnel. A technique of breaking ammonia into a hydrogen-nitrogen mixture is described in Section IV.

5. HOT-AIR SYSTEM

The hot-air tethered balloon could be built in a variety of shapes, but at present is available only in the natural shape. The envelope is built of an uncoated calendered nylon with excellent resistance to combustion products.

The gondolas are of welded tubing, providing two suspension points to the envelope rigging. The gondola mounts propane fuel tanks, flight instruments, space for pilot and passenger (if manned), and experimental equipment. The top of the gondola provides a mounting for the burner, which supplies the heat for buoyancy. Burner peak output is 2.4 million Btu/hour. Larger balloons use multiple burners.

The lower part of the balloon envelope is open to provide a wide clearance around the flame. The gondola is suspended from the envelope by steel cables, and the entire harness assembly is surrounded by a fabric skirt. The skirt protects the flame from winds, which could deflect the heat and damage the envelope.

Buoyancy is controlled by adjusting fuel flow through a dual path. The normal buoyancy level is set by metering the fuel through a needle valve. When a rapid increase in buoyancy is required, a toggle valve is operated to provide maximum fuel flow. A maneuvering vent near the top of the envelope can be opened by appropriate control lines to vent heat rapidly.

Inflation can be accomplished on open ground in winds of up to about 10 knots. With the smaller balloons, the gondola and burner - directed laterally into the supported envelope - can supply the initial bubble of hot air to erect the balloon. With the larger balloons, ground blowers with auxiliary burners inflate and erect the balloon, after which the gondola burner(s) take over.

At the conclusion of flight, after landing, two techniques are possible. After shutdown of the flame, a deflation port on the balloon topside can be pulled open to deflate the balloon. An alternate method is release of the balloon from the gondola, but restraint of the envelope with an outside rope to the top point of the balloon. The envelope is inverted at release from the gondola and rapidly deflated.

Auxiliary ground equipment can include blowers, burners, and propane storage equipment.

6. INFORMATION REQUIRED BY BALLOON CONTRACTOR

A typical inquiry sheet sent out by a tethered balloon system prime contractor to a potential customer is shown in Figure 20. The customer was requested to furnish all information on the sheet plus any additional information that would affect reliability and ultimate cost of the end product. Most of the table items are self-explanatory. Where further information is required, the remaining sections of this handbook should be studied for additional data.

7. AVAILABLE BALLOON SYSTEMS

All known industry sources directly involved with tethered balloon activities were requested to contribute engineering and performance data and description of specific designs and products for inclusion in this handbook. The data received was reduced to tabular form (refer to Tables I and II). The designs and equipment listed donot represent the limits of capabilities in the industry. Most balloon systems are rarely "off-the-shelf" items. The balloon systems are usually custom-tailored for a particular operation.

8. LIST OF MANUFACTURERS

The names and addresses of the balloon manufacturers listed in Tables I and II are given below.

Air Cruisers Div of Garrett Corp
P.O. Box 180
Belmar, New Jersey 07719

E. Bollay & Associates, Inc.
Boulder, Colorado

Dewey & Almy Chemical Division
62 Whittemore Avenue
Cambridge, Massachusetts 02140

Firestone Tire & Rubber Co.
General Office
1200 Firestone Parkway
Akron, Ohio

Robert Fulton Co.
Old Ridgebury Road
Danbury, Connecticut 06810

The General Tire & Rubber Co.
General Office
1708 Englewood Avenue
Akron, Ohio

The B.F. Goodrich Company
General Office
500 S. Main Street
Akron, Ohio 44311

Date ____________

Name of Person ____________________
Dept. or Title ____________________
Name of Company ____________________
Street Address ____________________
City, State, Zip Code ____________________
Telephone ____________________

1. Description of intended use

2. Payload Description

   a) Type

   b) Size

   c) Weight

   d) Other

3. Stability, Directional Requirements & Verticality of Payload or Balloon

4. Operating Altitude

   a) Above site

   b) Above MSL

5. Operating Site

   a) Area Description

   b) Fixed

   c) Mobile

   d) Will location be changed

6. Weather & Wind

   a) Climate

   b) Operating wind

   c) Survival wind

   d) Bedded down wind

   e) Temperature range

7. Flight Requirements

   a) Endurance per flight

   b) Frequency of flights

8. Balloon Life

   a) Operating

   b) Shelf life

9. Time Requirements

   a) Erection

   b) Ascent

   c) Descent

10. Number of Balloons Required

11. Winch Required

12. Tether Requirements

13. Delivery

14. Documentation

   a) Operation Handbooks

   b) Erection & Maintenance

   c) Other (drawings, specifications)

15. Training Program

16. Field Service

17. Military Security

Figure 20. Typical Balloon Manufacturer's Inquiry Sheet

Goodyear Aerospace Corporation
1210 Massillon Road
Akron, Ohio 44315

The Goodyear Tire & Rubber Co.
1144 East Market Street
Akron, Ohio 44316

Jalbert Aerology Laboratory
170 N.W. 20th Street
Boca Raton, Florida 33432

Litton Industries
(No longer in the tethered balloon business)

Raven Industries, Inc.
Box 1007, 205 E. 6th Street
Sioux Falls, South Dakota 57101

G.T. Schjeldahl Co.
P.O. Box 170
Northfield, Minnesota 55057

Sea-Space Systems, Inc.
1754 South Crenshaw Blvd.
Torrance, California 90501

Semco Balloons
2002 N. 11th Street
Coeur d'Alene, Idaho 83814

Uniroyal (Formerly U.S. Rubber Co.)
General Office and Product Information Center
Uniroyal, Inc., Rockefeller Center
1230 Avenue of The Americas
New York, New York 10020

Vee-Line Company
1650 Superior Avenue
Costa Mesa, California 92627

Winzen Research, Inc.
401 W. 84th Street
Minneapolis, Minnesota 55420

Table I. World War II Barrage Balloons - Single-Hull (Blimp) Shape, Hydrogen Inflated

Model	Envelope Volume (ft^3)	Net Static Lift (lb)	Maximum Hull Diameter (ft)	Confluence Point to Top of Env (ft)	Length (ft)	Altitude Capability (ft)	Maximum Design Wind (knots)
AIR CRUISERS							
D4	27,950	510.0	26.6	44.8	75.0	10,000	50
THE GENERAL TIRE & RUBBER CO.							
M-1, VLA	3,000	71.0	13.5	19.75	37.0	---	---
D4	30,600	576.0	28.25	43.82	80.0	9,500	50
THE B.F. GOODRICH COMPANY							
M-1, VLA	3,000	71.0	13.5	--	36.0	---	---
THE GOODYEAR TIRE & RUBBER CO.							
ZK2G	1,525	32.0	10.75	17.25	29.66	--	---
2700	2,700	50.0	12.75	---	35.0	---	--
M-1, VLA	3,000	71.0	13.5	---	37.0	---	---
D7	20,000	495.0	25.25	40.0	64.0	5,000	60
D-BB-1G	22,750	505.0	25.75	---	77.25	7,000	50
D8	23,500	589.0	27.0	---	68.0	6,200	---
ZKA	24,000	596.0	27.0	46.0	68.0	6,200	---
D3	24,950	400.0	27.3	45.65	77.5	7,500	50
D3	27,000	470.0	32.0	45.65	77.5	6,500	---
D5	30,500	620.0	29.0	48.5	82.5	7,500	50
D5	32,000	505.0	29.0	48.5	82.5	7,000	60
D-BB-6L	71,000	1340.0	36.8	63.4	109.73	15,000	50
D-6L-6F	71,000	1100.0	36.8	--	115.0	15,000	---
FIRESTONE TIRE & RUBBER CO.							
M-1, VLA	3,000	71.0	13.5	--	36.0	---	---
D6	28,350	515.0	27.75	45.65	83.92	7,500	50
U.S. RUBBER CO.							
M-1, VLA	3,000	71.0	13.5	--	36.0	--	---
D4	28,000	566.0	28.08	46.0	75.5	9,500	50

Table II. Modern Tethered Balloons (Sheet 1)

Model	Lifting Gas	Balloon Name	Envelope Volume (ft^3)	Shape	Net Static Lift (lb)	Dynamic Lift: Pounds	Dynamic Lift: At Wind (knots)	Dynamic Lift: At Alt (knots)	Max Hull Diameter (ft)
E. BOLLAY & ASSOCIATES, INC.									
MAT Wing	Helium	MAT	112	Airfoil	5.0	---	---	---	N/A
DEWEY & ALMY CHEMICAL DIVISION									
7080	Helium	Kytoon	48	Single hull	1.3	4.7	17	SL	3.3
8000		Kytoon	82	Single hull	2.0	6.0	17	SL	4.1
N-100		Darex	9.2	Spherical	0.6	N/A	N/A	N/A	2.6
N5-10-350			66		2.6				5.0
N5-15-500			113		5.8				6.0
N5-18-1065			206		10.3				7.3
N5-24-1750			422		22.9				9.3
N5-28-2400			660		36.2				10.8
N5-42-7000			2,250		125.0				16.3
ROBERT FULTON COMPANY									
BUDA-2	Helium	Skyhook	180	Single hull	5.9	---	---	---	5.3
BUDA-3	or		250		9.2	---	---	---	6.2
BUED-7&7-1	hydrogen		725		34.0	---	---	---	8.6
BUED-12&12-1			1,275		55.0	---	---	---	10.3
GOODYEAR AEROSPACE CORPORATION									
---	Helium	Vee	6	Double hull	0.20	---	---	---	4.5
351Z001		Vee	400		10	---	---	---	5.0
352Z000-001		Vee	700		15	---	---	---	6.0
628A000-003		Boomerang	2,000		110	---	---	---	9.5
8017-100		---	6,000	Single hull	172	---	---	---	17.0
342Z000-001		Vee	6,500	Double hull	116	---	---	---	12.0
359Z000-001		Vee	8,000		156	---	---	---	11.5
350Z001		Vee	14,000		250	---	---	---	15.0
GZ349		TVLF No. 6	75,000		1,400	---	---	---	27.0
GZ349		TVLF No. 8	92,000		1,800	---	---	---	27.0
GZ356		Vee	90,000		2,300	---	---	---	26.9
GZ355		Vee	180,000		3,400	---	---	---	34.0
JALBERT AEROLOGY LABORATORY									
J-2D	Helium	None	600	Single hull	10	---	---	---	8.3
J-5D			850		10	---	---	---	9.0
J-7D			1,100		15 - 18	---	---	---	9.75
J-8D	or		1,500		25 - 30	---	---	---	10.0
J-9D			2,100		50	---	---	---	12.0
J-9AD-62			3,400		100	---	---	---	13.75
J-10	hydrogen		5,000		150	---	---	---	15.75
LITTON INDUSTRIES									
---	Helium	38-ft Spherical	28,200	Spherical	1,188	N/A	N/A	N/A	38.0
---	Helium	Circus Day	55,000	Spherical	1,745	N/A	N/A	N/A	46.0
RAVEN INDUSTRIES INC									
S-50A	Hot air	Vulcoon	60,000	Natural	765	N/A	N/A	N/A	50.0
S-50P			60,000		765	N/A	N/A	N/A	50.0
S-60			106,000		2,150	N/A	N/A	N/A	60.0
625 XD-5-3	Helium	Aerokite	625	Single hull	29	---	---	---	7.0

Table II. Modern Tethered Balloons (Sheet 2)

Confluence Point to Top of Env (ft)	Length (ft)	Max Width (ft)	Max Design Wind: Flying (knots)	Max Design Wind: Bedded-Down (knots)	Altitude Capability (ft)	Tether Weight (lb/ft)	Tether Strength (lb)	Remarks
---	---	---	---	---	5,000	---	---	Mylar balloon wing system.
3.4	8.5	4.0	20	45	1,000	0.020	220	Nylon envelope and fins.
4.1	10.7	5.17	20	45	1,000	0.020	220	Neoprene bladder.
N/A	N/A	N/A	15	60	500	---	---	Neoprene expandable bal-
↓	↓	↓	15	60	1,000	0.020	220	loons. Can be clustered.
			15	60	1,800	0.020	220	Can be fitted with auto-
			15	60	5,000	0.020	220	matic gas-tight valves.
			15	60	15,000	0.020	220	
			15	40	10,000	0.020	220	
			15	40	20,000	0.020	220	
9.0	16.5	6.5			200 500	0.008	1,000	Personnel rescue system.
11.0	21.7	6.5			200 500	0.008	1,000	All balloons have ball-
14.0	26.9	7.1			500 1000	0.008/0.050	1,000/6,000	check filler valve and vis-
17.0	33.9	7.1			500 1000	0.008/0.050	1,000/6,000	ual indicator.
---	4.5	3.17	---		250	---	---	Mylar film construction.
---	18.0	13.0	30		500 800	---	140	---
---	20.0	19.0		---	500 800	---	---	---
17.5	24.0	24.0	30	---	1,000	---	---	Mylar, 1 mil.
25.5	46.6	21.0	30	---	2,000	0.0166	2,100	Communication package support.
---	46.0	32.0	50	---	1,500	---	---	---
26.5	51.0	36.0	50	---	5,000	0.0278	3,200	---
---	59.0	41.0	35	---	9 000	0.046	2,600	---
50.0	105.0	72.0	50	---	5,000	0.190	≈14,000	Communication package support.
50.0	108.0	71.3	50	---	10,000	0.190	≈14,000	Communication package support.
---	128.5	70.7	---	---	---	---	---	---
---	162.0	88.0	---	---	---	---	---	---
---	19.0	---	40	---	---	---	---	All balloons have dilation sys-
---	23.7	---	40	---	---	---	≈60	tem. Fin assembly is re-
---	24.5	---	40	---	---	---	---	movable.
---	29.3	---	40	---	---	---	---	
---	32.5	---	40	---	---	---	---	
---	37.5	---	40	---	---	---	---	
---	40.0	---	40	---	---	---	---	
N/A	N/A	N/A	25	---	7,000	---	---	Manufacturer no longer in bal- loon business. These balloons
N/A	N/A	N/A	25 at alt	---	12,000	---	5,000	in AFCRL inventory at Hollo- man AFB. 3.5 oz/yd^2 Dacron-Tedlar laminate.
67.0	N/A	N/A	15	N/A	5,000	---	---	Three to four hours on 44 gal propane. Other tankage avail- able. Unmanned remote con- trol gondola available. Envel- ope is 1.6 oz/yd^2 hi-tenacity nylon.
67.0	N/A	N/A	25	N/A	5,000	---	---	S-50 with on-board blower for superpressure.
80.0	N/A	N/A	18	N/A	8,000	---	---	---
12.0	22.4	9.0	50	---	6,000	---	---	Mylar bi-laminate or film-fabric, 2 oz/yd^2. This design repre- sents family of 100 to 3000 cubic foot balloons.

Table II. Modern Tethered Balloons (Sheet 3)

Model	Lifting Gas	Balloon Name	Envelope Volume (ft³)	Shape	Net Static Lift (ft)	Dynamic Lift Pounds	At Wind (knots)	At Alt (knots)	Max Hull Diameter (ft)
RAVEN INDUSTRIES INC (Continued)									
16.5-3-5	Helium	Aerocap	9,000	Single hull	316	800	40	1,000	16.5
32-3-5		Aerocap	50,000		900	1,300	30	10,000	32.0
250K01		---	250,000	Natural	14,000	N/A	N/A	N/A	82.0
530K02		---	530,000	Natural	25,000	N/A	N/A	N/A	104.0
G.T. SCHJELDAHL CO.									
---	Helium	Schjel-minnow	8	Single hull	0.25	0.75	25	200	2.0
---		None	650	Class "C," FR 4:1	25	25	25	1,500	7.5
S009500			775	Class "C," FR 3.5:1	20	27	20	1,000	7.5
S009700			1,500	Class "C," FR 3.5:1	46	45	20	3,000	9.5
S009800			5,300	Class "C," FR 3.5:1	206	120	20	5,000	14.0
---			7,820	Modified "C," FR 3.3:1	513	727	25	5,000	17.0
17,000 ft³			17,000	Class "C," FR 3:1	673	---	---	---	20.0
---			69,000	Natural	4062	N/A	---	---	55.0
SEA-SPACE SYSTEMS, INC. NO DATA AVAILABLE									
SEMCO BALLOONS									
One-Man	Hot air	Semco	30,000	Natural	225 + fuel	N/A	N/A	N/A	40.0
Four-Man	Hot air	Semco	91,000	Natural	650 + fuel	N/A	N/A	N/A	55.0
VEE-LINE COMPANY									
---	Helium	Dart	350	Delta V	14.75	---	---	---	---
---			400		17.00	---	---	---	---
---			500		22.25	---	---	---	---
---			600		26.50	---	---	---	---
---			750		32.50	---	---	---	---
---			1,000		44.50	---	---	---	--
---			1,250		55.50	---	---	---	---
---			1,500		66.75	---	---	---	---
---			2,000		89.00	---	---	---	---
---			4,000		178.00	---	---	---	---
WINZEN RESEARCH, INC. NO DATA AVAILABLE									

Table II. Modern Tethered Balloons (Sheet 4)

Confluence Point to Top of Env (ft)	Length (ft)	Max Width (ft)	Max Design Wind Flying (knots)	Max Design Wind Bedded Down (knots)	Altitude Capability (ft)	Tether Weight (lb/ft)	Tether Strength (lb)	Remarks
24.0	57.9	22.0	40	60	4,000			Laminated or coated fabric en veloped 4 to 7 oz/yd^2. This design representative of fam ily of 3,000 to 30,000 cubic foot balloons.
50.0	96.0	50.0	45	60	10,000			Envelope nominally 7.5 oz/yd^2 hypalon coated nylon. Repre sentative of a family of 30,000 to 150,000 cubic foot balloons.
95.0	N/A	N/A	30	60	6,000			Logging balloon. 11 oz/yd^2 neoprene-coated Dacron.
	N/A	N/A	35	70	6,000			Logging balloon. 12 oz/yd^2 neoprene-coated Dacron.
7.0	8.75	- - -	25	N/A	SL - 200	0.00005	20	0.500-mil aluminized Mylar, low cost, marker balloon.
11.0	30.0	- - -	25	50	SL - 1,800	0.007	750	Mylar-Dacron, 2.1 oz/yd^2 en velope. See Notes 1 and 2.
11.0	26.0	- - -	40	70	SL - 2,500	0.007	750	Nylon-urethane, 4.7 oz/yd^2 en-velope. See Notes 1 and 3.
14.0	33.0	- - -	40	70	SL - 3,600	0.009	1,200	Nylon-urethane, 4.7 oz/yd^2 en-velope. See Notes 1 and 3.
21.0	45.0	- - -	40	70	SL - 5,000	0.010	2,400	Nylon-urethane, 4.7 oz/yd^2 en-velope. See Notes 1 and 3.
26.0	54.0	- - -	25	50	SL - 5,000	0.028	3,000	Nylon-neoprene, 7.5 oz/yd^2 en-velope. See Notes 1 and 2.
30.0	72.0	- - -	60	80	SL - 10,000	- - -	24,000	Nylon-urethane, 6.5 oz/yd^2 en-velope. See Notes 1, 4, and 5.
81.0	N/A	N/A	50	N/A	SL - 15,000	0.124	13,500	Mylar scrim, 1.77 oz/yd^2 envel ope. Tether is a 14,000 foot antenna.
55.0	N/A	N/A	15	N/A	20,000	- - -	- - -	Type certificated for free flight.
85.0	N/A	N/A	15	N/A	20,000	- - -	- - -	Can be tethered.
- - -	- - -	19.0	- - -	- - -	- - -	- - -	- - -	Design incorporates external dilation system.
- - -	- - -	20.0	- - -	- - -	- - -	- - -	- - -	
- - -	- - -	22.7	- - -	- - -	- - -	- - -	- - -	
11.0	24.0	23.5	65	75	10,000*	- - -	- - -	
- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	
- - -	- - -	28.5	- - -	- - -	- - -	- - -	- - -	
- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	
- - -	- - -	31.0	- - -	- - -	- - -	- - -	- - -	
- - -	- - -	35.0	- - -	- - -	- - -	- - -	- - -	
- - -	- - -	42.0	- - -	- - -	- - -	- - -	- - -	
								Design and build balloons of poly-ethylene and polyurethane film.

NOTES
1. Barometric switch set for design altitude to open up reinforced hole for deflation.
2. No-wind trim 10° nose up.
3. No-wind trim 10° to 15° nose up.
4. Helium relief valve.
5. No-wind trim can be adjusted in flight, 5° to 12° nose up.

*With dynamic lift.

(Page 30 is blank)

SECTION III

ENVELOPE MATERIALS

1. GENERAL

Balloon envelopes are made of film-fabric laminates, two-ply fabric laminates, or single films, depending on the application of the particular balloon. The exterior coating usually is aluminized polyurethane or aluminized Hypalon to protect against the weather and ultraviolet radiation.

Dacron/Mylar laminates or nylon/Mylar laminates have been most recently used in balloon envelopes. The cloth provides the necessary strength, with the Mylar film acting as the gas barrier. This type of laminate is used where maximum net static lift is required.

A laminate of straight and biased cloths coated with polyurethane, neoprene, and butyl or other elastomer materials is used for balloon envelopes where ruggedness and strength are needed. The cloth provides the strength; the coatings saturate the cloth and act as the gas barrier, and also provide weather and ultraviolet protection.

Materials within the present day state of the art can be preselected with a high degree of confidence to fulfill specific material requirements of proposed balloon systems. These materials fall within one of the following categories:

(1) Unsupported films
(2) Film-cloth laminates
(3) Cloth, calendered but uncoated (hot-air application)
(4) Single-ply coated fabrics
(5) Multi-ply coated fabrics

New materials of all types are constantly being sought and tested, individually and in combinations, to provide balloon materials that are stronger, lighter, and more economical. Fabrication processes are under continual scrutiny to develop better techniques and to improve the quality.

2. FABRICS

The use of a flexible fabric in pressure-rigidized structures requires that the fabric perform two basic functions:

(1) Support the structural loads (cloth).

(2) Contain the pressurizing media (elastomer).

3. CLOTH

Woven cloth is the usual form of the load-carrying member. The cloth is woven from filaments that can be made from a multitude of materials. Some of the more common filaments are listed below.

Cotton	Orlon
Rayon	Acrilan
Acetate	Polypropylene
Nylon	Polyethylene
Dacron	Fiberglas

Some exotic filaments that have been woven into cloth form include Teflon, high-temperature nylons, metals, nickel alloys, carbon, boron, etc. This discussion will center

mainly on the materials most often used for ordinary applications within temperature extremes of -35° to +140°F.

Since normally there can be several hundred yarn intersections in each square inch of woven fabric, there exists a wide range of fabric weave patterns that designers have developed. There are four basic weaves that are most often used in weaving cloths. These four types of weaves are described below.

(1) Plain Weave. This is the simplest and most common weave, repeating on two warp and two filling yarns. It is also known as a "one up and one down" weave, expressed by 1/1.

(2) Basket Weave. The basket is a modification of the plain weave except that two or more warp and filling yarns are woven as one. A common expression to describe it is, for example, "two by two basket weave," expressed by 2/2.

(3) Twill Weave. Twill weaves produce diagonal or "twill" lines running upward to the right (or left) on the fabric face. The diagonals are accomplished by moving the yarn intersections one pick higher on successive warp yarns. In some cases the intersections are moved more than one pick, thus producing steep twills, broken twills, and the like. Warp twills contain more warp yarn on the fabric face. Even-sided twills have an equal number of warp and filling floats up, and therefore have equal amounts of warp and filling on the fabric face. Similarly, filling twills have more filling yarns on the face. In the herringbone twill, the twill line runs up to the right and then goes down to the right.

(4) Satin Weaves. Satin weaves produce a smooth fabric surface by carrying the warp (or the filling) uninteruptedly on the fabric surface over many filling (or warp) yarns. Intersections between warp and filling are kept to a minimum, usually just sufficient to ensure that the fabric will firmly hold together. The long warp (or filling) "floats" on the fabric face cause the light to be uniformly reflected, and so satin weaves are usually smooth and shiny - particularly if the yarn is continuous filament and of low twist.

A comparison of the basic weaves, which are shown in Figure 21, is given in Table III. A comparison of the more predominately used filaments in woven cloth is given in Table IV.

Table III. Comparison of Basic Weaves

Type of Weave	Advantages	Disadvantages
Plain	Tightest weave; lowest porosity; low racking.	Low abrasion resistance
Basket	Square woven; higher yarn count possible.	High bulk
Twill	Softer and more flexible; higher yarn count possible.	Higher racking[a]
Satin	Most flexible; highest yarn count; smoothest surface; high abrasion resistance.	Highest racking[a]

[a]Racking is the distortion of warp-fill pattern out of square due to bias loading.

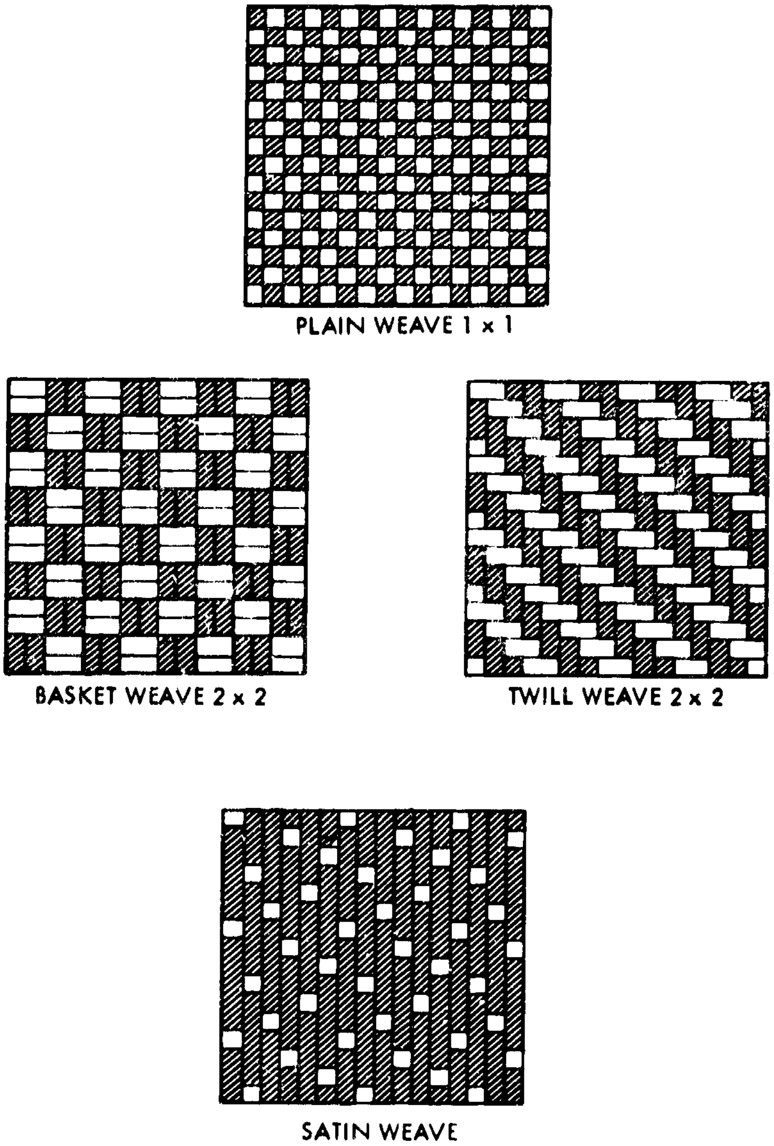


Figure 21. Basic Weaves

Table IV. Comparison of Filaments

Properties	Rayon	Nylon	Dacron
Breaking tenacity, grams/denier . . .	2.4 to 3.2	4.6 to 5.9	4.4 to 5.0
Tensile strength, psi	46 to 65,000	67 to 86,000	77 to 88,000
Breaking elongation, percent	15 to 20	26 to 32	19 to 25
Elastic recovery, percent	97 at 2%	100 at 2%	97 at 2%
Specific gravity . .	1.46 to 1.52	1.14	1.38
Water absorbency at 70°F & 65% RH, percent	13	4.5	0.4
Effect of heat . . .	Does not melt. Loses strength at 300°F. Decomposes at 350° to 400°F.	Melts at 482°F. Yellows slightly at 300°F when held for 5 hrs.	Melts at 480°F.
Effect of acids . . .	Similar to cotton; hot dilute or cold concentrated disintegrate fiber.	Boiling in 5% hydrochloric acid ultimately causes disintegration. Dissolves with at least partial decomposition in cold concentrated solutions of hydrochloric, sulfuric, and nitric acids.	Good resistance to most mineral acids. Dissolves with at least partial decomposition by concentrated solutions of sulfuric acids.
Effect of alkalis . .	Strong solutions cause swelling and reduce strength.	Substantially inert.	Good resistance to weak and moderate resistance to strong alkalis at room temperatures. Disintegrated by strong alkalis at boiling temperatures.
Effect of other chemicals	Attacked by strong oxidizing agents; not damaged by hypochlorite or peroxide bleaches.	Generally good resistance.	Generally good resistance. Excellent resistance to bleaches and other oxidizing agents.

Table IV. Comparison of Filaments (Continued)

Properties	Rayon	Nylon	Dacron
Effect of organic solvents	Generally insoluble; soluble in cuprammonium and a few complex compounds.	Generally insoluble, soluble in some phenolic compounds and in concentrated formic acid.	Generally insoluble. Soluble in some phenolic compounds.
Dyes used	Same as for cotton; medium and high tenacity are harder to dye.	Disperse and acid are usually preferred, but most other classes are also used.	Disperse (acetate), developed (azoic), and cationic (for some types), with carrier, or at high temperatures.
Resistance to mildew	Attacked.	Not attacked.	Not attacked.
Identification . . .	Does not melt. Burns readily with little ash. Insoluble in acetone.	Melts before burning, self-extinguishing. Insoluble in acetone or boiling NaOH solutions. Soluble in concentrated formic acid and xylenol.	Melts before burning. Soluble in hot metacresol, but not soluble in acetone or concentrated formic acid.

4. ELASTOMERS

The basic function of the elastomer compound is to provide the gas barrier for the inflated structure. At the same time, the elastomer covers the threads, thus providing sunlight and other weathering protection and a suitable bonding surface. The thickness of the elastomer on the outside of the cloth can be varied to provide the required amount of abrasion protection for "wear and tear" considerations. Some of the available elastomers are listed below.

Natural rubber	Teflon
Butyl	Hypalon
Neoprene	Viton
Polyurethane	Silicone

In addition, Mylar film has been laminated to cloths such as nylon and Dacron, thus providing an extremely impermeable fabric. The relative general properties of elastomer types are given in Table V.

5. FABRIC CONSTRUCTION

Various fabric construction techniques have been investigated and utilized for inflatable structures, such as free and tethered balloons and nonrigid airships. The selection of the fabric for this type of inflatable structure is based primarily upon the necessary skin strength required to resist deformations due to internal and external loads. Other important considerations have been service life, impermeability to gases, strength-to-weight ratio, and good packaging characteristics.

The most commonly used construction has been the elastomer coated fabrics. Here, multiple plies of cotton, nylon, or Dacron woven cloths were used, with the

Table V. Relative General Properties of Elastomers (Sheet 1)

Elastomer Types	Tensile	Tear	Abrasion	Impact (fatigue)	Flame	Heat	Cold (stiff)	Cold (brittle)
Natural Rubber	AB	B	AB	AB	D	CD +250°F	B	B -80°F
Styrene Butadiene Rubber (Buna S or GRS)	B	BC	AB	AB	D	C +275°F	BC	B -80° to -90°F
Isobutylene Isoprene Rubber (Butyl or GR-1)	C	B	B	C	D	BC +300°F	C	BC -50° to -80°F
Chloroprene Rubber (Neoprene or GR-M)	B	B	AB	B	B	C +300°F	C	BC -45° to -70°F
Polyurethane Elastomers (Adiprene, Chemigum SL, CX-1046)	A	A	A	B	CD	C +250°F	C	A -30° to -95°F
Nitrile Butadiene Rubber (Buna N)	BC	BC	AC	C	D	B +275°F	BC	BC -80° to -90°F
Silicone Rubbers	D	CD	CD	D	C	A +550°F	A	A -200°F
Chlorosulfonated Polyethylene (Hypalon)	BC	BC	AB	BC	B	BC +325°F	C	B -70° to -80°F
Fluorinated Elastomers (Fluorel, Kel-F, Viton)	BC	BC	B	BD	A	A +450°F	D	BC +10° to -40°F
Organic Polysulfide Rubbers (Thiokol, GR-P)	D	D	D	D	D	C +200° to +275°F	C	B -60° to -80°F

A = Exceptional, Outstanding, or Excellent B = Good C = Fair D = Poor

Table V. Relative General Properties of Elastomers (Sheet 2)

Ozone	Radiation	Gas Retention	Resistance - Oil, Weather, Chemical	Unsuitable For	Specific Gravity
D	BC	B	Highly resilient, low hysteresis, general purpose.	Contact with oils, ozone, strong oxidizing agents.	0.93
D	BC	B	General purpose rubber, not so resilient as natural, better resistance to aging.	Contact with oil, ozone, strong oxidizing agents.	0.94
AB	D	A	Weather, heat, ozone, chemical and solvent resistant, low air permeability.	Contact with oils.	0.92
AB	CD	AB	Weather resistant, fair oil resistance.	Temperature extremes, contact with aromatic oils and most fuels, long exposure to low temperatures.	1.24
A	B	A (R.T.)	Superior abrasion resistance, sunlight and ozone resistance, good oil resistance.	Contact with steam or hot water.	1.05 to 1.17
D	BC	B	Medium to good oil resistance, fair fuel resistance.	Contact with ozone, strong oxidizing agents.	0.99
A	D	B	Resistant to temperature extremes, fair oil resistance, properties constant from -60° to +500°F.	Contact with high pressure steam, aromatic oils, fuels, abrasion.	1.25
A	BC	AB	Weather, heat, ozone, and moderate oil resistance, good color possibilities.	Aromatic oils and most fuels.	1.10
A	BC	A	Resistant to oxidizing acids, fuels containing up to 30% aromatics, ozone, weather; excellent oil resistance.	Contact with diester lubricants, uses where material must be easily flexed at temperatures below 0°F.	1.40 to 1.85
A	BC	A	Excellent oil resistance, good resistance to aromatic fuels, excellent weather and ozone resistance.	Resistance to compression set particularly at temperatures above 100°F, uses where mercaptan odor would be objectionable, contact with oxidizing acids.	1.25 to 1.60

A = Exceptional, Outstanding, or Excellent B = Good C = Fair D = Poor

necessary weight of elastomer coating such as neoprene, to provide gas tightness and weatherability. With the multiple-ply coated fabrics, a straight and bias ply construction was found to be necessary to provide the shear stiffness required for maintaining the shape of a streamlined envelope. Early attempts at streamlined envelope construction with a single-ply coated fabric resulted in a distorted "banana" shape. The usual practice with a straight/bias ply construction is to orient the bias ply at 45 degrees, with the straight ply carrying the major hoop and longitudinal tension loads in the direction of its warp and fill threads. The bias ply is normally the outer one, to take the brunt of weathering.

Recent investigation and use have been made of balloon fabric consisting of Mylar film laminated to Dacron cloth and in some cases further coated with a pigmented polyurethane elastomer. This construction technique was used for a family of film-cloth laminates with weights varying from 1.5 to 7 ounces per square yard, and breaking strengths from 40 to 300 pounds per inch. Comparisons of strength-to-weight ratios, tear strength, and permeability to gases for unsupported films, film-cloth laminates, and coated fabrics are tabulated in Table VI and plotted in Figure 22.

The usual practice in the final selection of a balloon fabric is the result of compromise, where material properties desired are extreme light weight, high strength, impermeability to gases, and packageability, plus a specified service life contingent on known environmental exposure conditions. The various candidate materials that may be selected for a balloon fabric specification are described in the following paragraphs.

Table VI. Comparison of Film-Cloth Laminates, Coated Fabrics, and Unsupported Films

Properties	Polyethylene Film	Mylar Film	Capran Film	Mylar-Dacron Polyurethane Fabric	2-Ply Dacron-Neoprene Fabric
Typical application	Free balloon	Free balloon	Air shelter	Vee-Balloon	Nonrigid airship
Nominal weight, oz/yd^2	0.75/mil	1/mil	1/mil	4.15	11
Ultimate tensile, lb/in.	5/mil	20/mil	6.7/mil	75	134
Strength/weight, inches	139,000	415,000	139,000	385,000	253,000
Permeability (He), l/m^2/24 hr	43.3/mil	1.5/mil	1.7/mil	2	2
Tear strength (Goodyear 1" centerslit), lb	3.2/mil	1.7/mil	---	56	115
Tear strength, g/mil (Elmendorf)	170	15	75	---	---

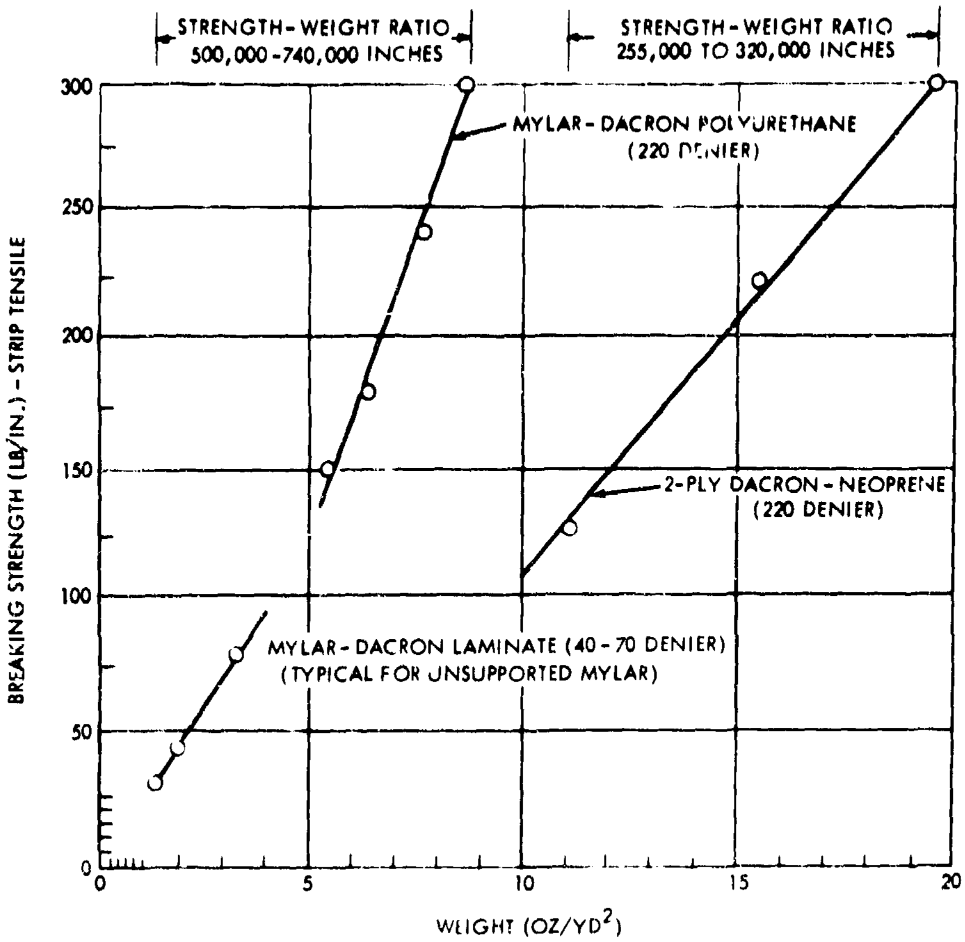


Figure 22. Strength-to-Weight Comparisons - Film Cloth Versus Elastomer Laminates

6. FILMS

Mylar polyester type film and Capran polyamide type film are the prime film candidate materials and would be used in combination with tightly woven cloth constructions on a balloon. Both films offer outstanding combinations of mechanical properties of high impact strength, flex life, and impermeability to gases. Both are considerably higher than polyethylene film for impermeability, and while the tear strength of Mylar is considerably lower than that of polyethylene film, Capran film tear strength is nearly as good. Both Mylar and Capran films exhibit a practical service temperature range adequate for most tethered balloon temperature environments. As both Mylar and Capran films have only fair resistance to ultraviolet, a balloon might require ultraviolet absorber type surface coating.

7. WOVEN CLOTHS

Due to the usual requirement for a high degree of dimensional stability in a balloon structure so as to maintain the desired aerodynamic shape, a flexible material exhibiting high initial modulus (resistance to initial stretch) is required. To provide an indication of efficiencies of finished woven cloths, yarn data have been plotted to show the stress-strain relationship of nylon, Dacron, and cotton yarn (see Figure 23). These plots indicate that the initial

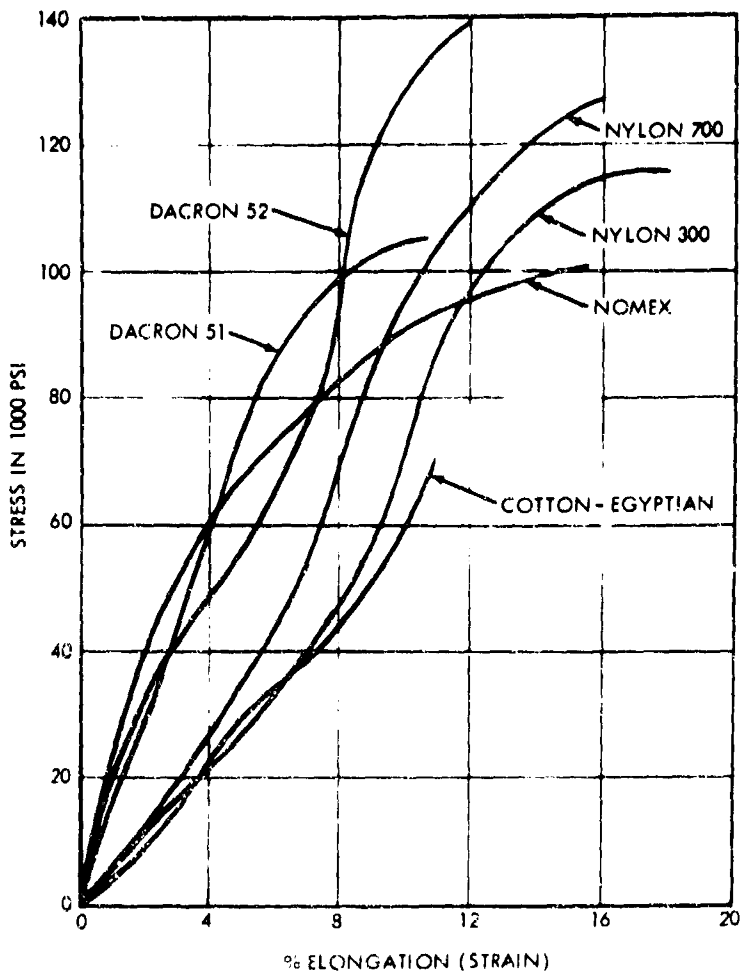


Figure 23. Stress-Strain Curves for Nylon, Dacron, and Cotton Yarn

modulus of Dacron yarn is high when compared with that of other textile fibers. As a result of past experience and the yarn survey, Dacron would be selected as the most promising basic fiber for cloth in a balloon film-cloth or coated cloth laminated construction. As to the cloth weave, a plain type weave with low twist filament yarns has been found to give the best adhesion with films and elastomer coatings.

8. COATINGS

For the one- or two-ply elastomer coated balloon fabrics, a minimum-weight polyurethane elastomer coating on Dacron cloth is good. This serves to facilitate joint construction for a more heavily loaded structure, by use of a wet cemented type joint. Dependent on whether radio frequency energy is to be reflected or transmitted, the proper pigmenting, such as aluminum or titanium dioxide, may be added to the coating for ultraviolet protection, and also solar heat reflectance to minimize superheat of the inflation gas. Past experience with effects of long time-weathering on fabrics has shown the lightweight film-cloth laminated type construction (Mylar-Dacron-polyurethane) to have 6 to 12 months' service life with the proper combination of coating weight and cloth weave. The heavier two-ply airship-type coated fabrics (Dacron-Neoprene-Hypalon) have been found to give up to 5 years' service if given proper maintenance.

9. DIFFUSION AND INFUSION

Diffusion and infusion are phenomena dealing with the loss of lifting gas and the increase of impurities within balloon envelopes and other similar gas-holding barriers. Diffusion describes the action of gases slowly escaping through a gas barrier material. Infusion describes the action of plain air going through the same barrier from outside to inside and mixing with the gases, thus changing the purity of the gas. Both diffusion and infusion take place at the same time, with a resulting gradual loss of lift. Diffusion and infusion take place with both hydrogen and helium and are the second largest lift losses after just plain gas leaks. When the losses are noted with a hydrogen balloon, the gas supply is simply replenished because of its comparative low cost. When losses are noted in a helium envelope, under some conditions, helium purification is sometimes necessary. During a single purification of the helium within a non-rigid airship envelope, water (to the extent of quite a few gallons) has been removed from the helium to prove out the theory of infusion into a constantly pressurized envelope. The amount of diffusion and infusion on any particular envelope varies according to the type of barrier, the amount of barrier, the use or abuse the barrier has received, and the age of the material where aging is a factor. Most tethered balloon applications have required very small or no application of helium purification; therefore, diffusion and infusion records do not exist. Every balloon system operator should understand that these lift losses do exist.

10. TESTING LAMINATED FABRICS

The weight, width, or breaking strength of laminated fabrics is usually tested in accordance with the American Society of Testing Materials (ASTM) specifications. The ASTM tests are normally accepted standards throughout the fabric-producing industry.

11. TESTING PERMEABILITY AND PLY ADHESION

When the diffusion rate or ply adhesion tests are required on envelope fabric, they are normally conducted as outlined in specification Fed. CCC-T-191. The specification also describes the type of instruments used for the tests. Normally a series of tests requires separate pieces or samples of envelope material. A recommended maximum allowable diffusion rate for a good envelope would not exceed 2 liters per square meter in 24 hours. A recommended minimum allowable ply adhesion rate is 3 pounds per inch for good fabric.

12. AVAILABLE ENVELOPE MATERIALS

Tables VII and VIII list the envelope materials available from the manufacturers who furnished data for this handbook. The names and addresses of the manufacturers listed in the tables are given below.

Arvey Corp., Lamcote Div.
3500 N. Kimball Ave.
Chicago, Illinois 60618

Haartz-Mason, Inc.
270 Pleasant Street
Watertown Massachusetts 02172

Reeves Vulcan Division
P.O. Box 5216
Akron, Ohio 44313

G.T. Schjeldahl Co
P.O. Box 170
Northfield, Minnesota 55057

Semco Balloons
2002 N. 11th St.
Coeur d'Alene, Idaho 83814

Standard Packaging Co.
1 Lisbon Street
Clifton, New Jersey 07013

Vee Line Corp.
1650 Superior Ave.
Costa Mesa, California 92627

Table VII. Available Coated Fabric Materials

Manufacturer	Haartz-Mason				Reeves					
Code No.	1763 N0512		1753-D2230		15240		15611		15614	
Description	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt
Construction:										
Coating	Hypalon[a]	0.8	Hypalon[a]	0.8	Urethane[b]	1.8	Urethane[c]	1.6	Urethane[b]	2.4
Coating	Neoprene	0.6	Neoprene	1.9			-		-	--
Cloth - bias	Dacron	1.3	Dacron	3.1						--
Coating	Butyl	1.8	Butyl	3.7	-	-				---
Cloth - straight	Dacron	1.3	Dacron	3.1	Dacron	2.4	Nylon	2.0	Nylon	4.0
Coating	Neoprene	0.8	Neoprene	0.9	Urethane	1.8	Urethane	1.0	Urethane	0.5
Total - oz/yd^2		6.6		13.5		6.0		4.6		6.9
Remarks	Two-ply		Two-ply		One-ply		One-ply		One-ply	
Physical Properties:										
1. Weight, oz/yd^2 ($\pm$0.5 oz/yd^2)	6.6		13.5		6.0		4.6		6.9	
2. Width, in., min	43		42		65		52		40	
3. Breaking strength, lb/in. min (WxF)	60 x 70		200 x 220		100 x 85		87 x 87		210 x 185	
4. Ply adhesion, lb/in., min	5.0		5.0						---	
5. Coating adhesion, lb/in., min	7.5		7.5		10.0		7.0		8.0	
6. Permeability (He), l/m^2/24 hr, max	2.0		2.0		3.0		3.0		3.0	
7. Bias seam peel, lb/in., min	4.0		4.0				---		---	

NOTE: Weight is given in oz/yd^2. [a]Aluminum [b]Yellow [c]Neutral

Table VIII. Available Laminated Fi

Manufacturer	Arvey Corporation								Standard Packaging				Haartz-Ma
Code No.	R-V-CX-27B		A-3512		R-V-CX-6		A-3617		Unknown		Unknown		1758-D-02
Description	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup
Construction:													
Film	---	---	Mylar	0.3	Mylar	0.36	---	---	---	---	Mylar	0.25	---
Adhesive	---	---	Urethane	0.2	Urethane	0.08	---	---	---	---	Polyester	0.30	---
Film	Mylar	0.5	Poly-ethylene	0.4	Mylar	0.36	Capran	0.75	Tedlar	0.5	---	---	Mylar
Adhesive	Polyester	0.5	---	---	Polyester	0.43	Polyester	0.60	Polyester	0.3	---	---	Polyester
Coating	---	---	---	---	---	---	---	---	---	---	---	---	Urethane
Cloth	Dacron	0.6	---	---	Dacron	0.80	Nylon	1.14	Fiberglass	0.6	Nylon	1.00	Dacron
Coating	---	---	---	---	---	---	---	---	---	---	---	---	Urethane
Total - oz/yd^2		1.6		0.9		2.03		2.49		1.4		1.55	
Remarks	Clear		Aluminized Mylar, orange pigmented urethane		Orange pigmented urethane		Clear		Aluminized Tedlar		Aluminized Mylar, orange nylon		Auminum pi mented ureth
Physical Properties:													
1. Weight, oz/yd^2 (±0.25 oz/yd^2)	1.6		0.9		2.03		2.49		1.4		1.55		4.8
2. Width, in., min	54		54		41		40		36		34		44
3. Breaking strength, lb/in min (WxF)	45 x 25		4 x 4		41 x 41		45 x 45		---		40 x 40		45 x 50
4. Ply adhesion, lb/in., min	3.0		3.0		3.0		3.0		2.0		2.0		5.0
5. Coating adhesion, lb/in., min	---		---		---		---		---		---		7.5
6. Permeability (He) l/m^2/24 hr, max	2.0		1.0		2.0		2.0		---		---		2.0

NOTE: Weight is given in oz/yd^2.

(Page 44 is blank)

A

ilable Laminated Film-Fabric Materials

ng		Haartz-Mason		Vee Line				Semco		G. T. Schjeldahl					
known		1758-D-0226		Chrome-Tec 150		Chrome-Tec RS-2		N-11-135		GT-31		GT-1012-2		GT-112	
)	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt	Layup	Wt
	0.25	---	---	---	---	---	--	---	---	Mylar	0.25	Mylar	0.36	Mylar	0.35
er	0.30	---	---	---	---	---	--	---	---	Polyester	0.40	Polyester	0.62	Polyester	0.16
	---	Mylar	0.5	Saran	2.2	---	---	Saran	2.2	Mylar	0.25	---	---	---	---
	---	Polyester	0.4	---	---	---	---	---	---	Polyester	0.45	---	---	---	---
	---	Urethane	1.1	---	---	---	---	---	--	---	---	---	---	---	---
	1.00	Dacron	1.3	Nylon	1.1	Composite	2.4	Nylon	1.1	Dacron	0.80	Dacron	0.60	Dacron*	0.28
	---	Urethane	1.5	---	---	---	---	---	---	---	---	Dacron*	0.19	---	---
	1.55		4.8		3.3		2.4		3.3		2.15		1.77		0.79
zed My- nge nylon		Auminum pigmented urethane		Clear		Composite Nylon - Type 304 stainless steel yarn		Clear		Clear		*Adhesive - coated scrim. Mylar-scrim - scrim laminate.		*Flying thread loom type	
5		4.8		3.3		2.4		3.3		2.15		1.77		0.79	
		44		---		---		34.5		41		60		---	
x 40		45 x 50		53 x 48		97 x 95		53 x 48		40 x 40		100 x 25		55 x 20	
		5.0		---		---		---		3.0		1.5		---	
-		7.5		---		---		---		---		---		---	
-		2.0		---		---		---		1.0		1.6		---	

(Page 44 is blank)

B

SECTION IV

LIFTING GASES

1. GENERAL

This section covers the science of aerostatics and the procedures for determining a required balloon displacement. The handling problems and history of various lifting gases are also described. The information in this section is supplemented by detailed information in Appendixes I and II.

2. AEROSTATICS

a. General

The science of aerostatics, which deals with flotation of lighter-than-air aircraft by the buoyancy arising from the differences in weight between the air and the inflating gas used, is discussed in the following paragraphs. Information from War Department Technical Manual 1-325 (Reference 5) is included in this discussion.

b. Atmosphere

For a complete understanding of the subject of aerostatics, it is necessary first to make a brief study of the atmosphere, which is the sustaining medium.

The atmosphere is defined as the gaseous envelope which surrounds the earth. It is composed of a mixture of gases, and at mean sea level under average conditions, excluding water vapor, its approximate composition by volume is as follows:

Nitrogen	78.00%
Oxygen	20.95
Argon	0.91
Carbon dioxide	0.03
Hydrogen	0.01
Other gases	0.10
Total	100.00%

As can be seen from the foregoing, nitrogen and oxygen are the two principal components, hydrogen and other gases being present in very small quantities. At an altitude of about 30,000 feet the amount of hydrogen is about double that at the earth's surface.

The atmosphere is subject to changes in condition, but only in a very small degree to changes in composition near the earth's surface. For purpose of the study of aerostatics, it is assumed that pressure, temperature, and humidity of the atmosphere alone affect aerostatic computations. Of these three, the first two affect only the condition of the atmosphere, while the third affects both condition and composition. Any effects of latitude upon gravity will be neglected as they are negligible for practical purposes. The causes which operate to alter pressure, temperature, and composition of the atmosphere are treated in the study of meteorology. These causes can be traced, and to a certain extent, changes in the condition of the atmosphere can be foretold. The barometric pressure shows a rapid drop during ascent up to about 6 miles, where the trend changes less rapidly; also about half of the earth's air, by weight, lies below 20,000 feet, or less than 4 miles. The pressure is reduced by approximately one-half for every 3.6 miles of ascent.

c. Physical Properties of Gases

As it is necessary to use gases for inflation of lighter-than-air aircraft, it is necessary

to make a study of some of their physical properties. The ideal balloon would be one containing a vacuum, but due to the tremendous value of the atmospheric pressure it is impossible to build a balloon strong enough to contain a vacuum and yet be light enough to float in the atmosphere. In reality the gas in a balloon (by opposing the external or atmospheric pressure) serves as a medium by which internal pressure or shape is maintained in the balloon or airship envelope.

Both liquids and gases are fluids. A fluid does not offer permanent resistance to forces tending to produce a change of shape, that is, its modulus of shear is very low. The resistance or friction to distortion is called the viscosity of the fluid. The three important differences between gases and liquids are as follows:

(1) Gases are compressible.

(2) Gases change volume rapidly with changes in temperature.

(3) Gas atoms or molecules appear to have the same electrical charges or to possess the property of repelling each other.

The weight of the unit of volume of a body is called the "density" of that body. The density is thus the force of gravity acting on the mass of a unit volume.

$$\text{Density} = \frac{\text{weight of body}}{\text{volume of body}}$$

In the metric system the unit of volume is the cubic meter and the unit of force the kilogram; the density is expressed in kilograms per cubic meter. For water and air the densities are, respectively, 1,000 kilograms per cubic meter and 1.23 kilograms per cubic meter. In the English system of units, the unit of volume being the cubic foot and the unit of force the pound, the density of gas is expressed in pounds per cubic foot. For air under standard conditions, the density is 0.07651 pound per cubic foot, or 76.51 pounds per 1,000 cubic feet. In the case of gases, conditions of pressure and of temperature are of such importance that it is impossible for them not to be taken into consideration. The gas used for purposes of comparison is air under established conditions of purity. The composition of atmospheric air is remarkably constant, as previously stated, except for the proportion of water vapor it contains. This variability is eliminated by taking dry air as a standard of comparison. In determining the standard densities or specific gravities of air and other gases, the temperature is supposed to be maintained at 59°F and under a constant pressure of 760 millimeters of mercury (29.92 inches). Under these conditions, the standard density of dry air is 1.23 kilograms per cubic meter (0.07651 pound per cubic foot) and is the standard of comparison from which specific gravities of all gases are determined.

The ratio of the density of a given substance to the density of some substance adopted as a standard, buth being subjected to identical conditions of pressure and temperature, is known as the specific gravity of the given substance. This ratio is independent of the system of units employed, but both densities must be expressed in similar units. Dry air is the standard of comparison for determining the specific gravity of gases. The specific gravity of a gas is the ratio between the weight of a unit volume of that gas and the weight of the same volume of dry air taken under the same conditions of temperature and pressure.

$$S_g = \frac{\text{weight of unit volume of gas}}{\text{weight of unit volume of air}}$$

For instance, the densities under standard conditions of dry air and hydrogen are, respectively, 0.07651 and 0.00532 pound. Therefore, the specific gravity of H is

$$S_g = \frac{0.00532}{0.07651} = 0.069$$

The ratio thus obtained is practically constant whatever may be conditions of temperature and pressure. In other words, the coefficients of expansion of all gases are the same.

The following are the constant densities and specific gravities for some gases under standard conditions of pressure and temperature:

(1) Standard Density
  (a) Air = 0.07651 lb/cu ft
  (b) Hydrogen = 0.00532 lb/cu ft
  (c) Helium = 0.01056 lb/cu ft

(2) Average density of illuminating gas = 0.0306 lb/cu ft

(3) Specific Gravity
  (a) Dry air = 1
  (b) Pure hydrogen = 0.069
  (c) Pure helium = 0.138

(4) Average specific gravity of illuminating gas = 0.4 (approx)

  NOTE: Gas produced in large quantities as for inflation of balloons cannot be obtained chemically pure in manufacture. Its specific gravity will therefore be higher than the preceding.

It must be made clear that "standard conditions" as defined by aeronautical or aerostatic sources, by physicists or chemists, or by the compressed-gas industry are by no means identical. Even within a given field, standard conditions may have changed over the years. Great care should be exercised in the use of densities and weights of air or any other gas as given by any reference source. Correlation of data from different sources may require correction to common standard conditions before using the data.

d. Laws Governing Aerostatics

The science of aerostatics is derived from the following laws and fundamentals:

(1) Archimedes' principle - The buoyant force exerted upon a body immersed in a fluid is equal to the weight of the fluid displaced.

(2) Boyle's law - At constant temperature the volume of a gas varies inversely as the pressure.

(3) Charles' law - At constant pressure the volume of a gas varies directly as the absolute temperature.

(4) Dalton's law - The pressure of a mixture of several gases in a given space is equal to the sum of the pressures, which each gas would exert by itself if confined in that space.

(5) Joule's law - Gases in expanding do no interior work.

(6) Pascal's law - The fluid pressure due to external pressure on the walls of the containing vessel is the same at all points throughout the fluid.

A complete discussion of the laws of aerostatics is given in Appendix I.

3. TYPES OF LIFTING GASES

The various types of lifting gases are listed in Table IX in the order of lift capability in pounds per cubic foot. Specific lift of gases at various altitudes is shown in Figure 24.

Table IX. Lift Ratios of Gases

Type of Gas	Ratio to Helium
Hydrogen	1.08
Helium	1.00
Coal gas (hydrogen, carbon monoxide, methane)	0.73
Ammonia	0.48
Hot air (see Figure 27)	0.312[a]

[a]When $T_b - T_a = 190^{\circ}F$

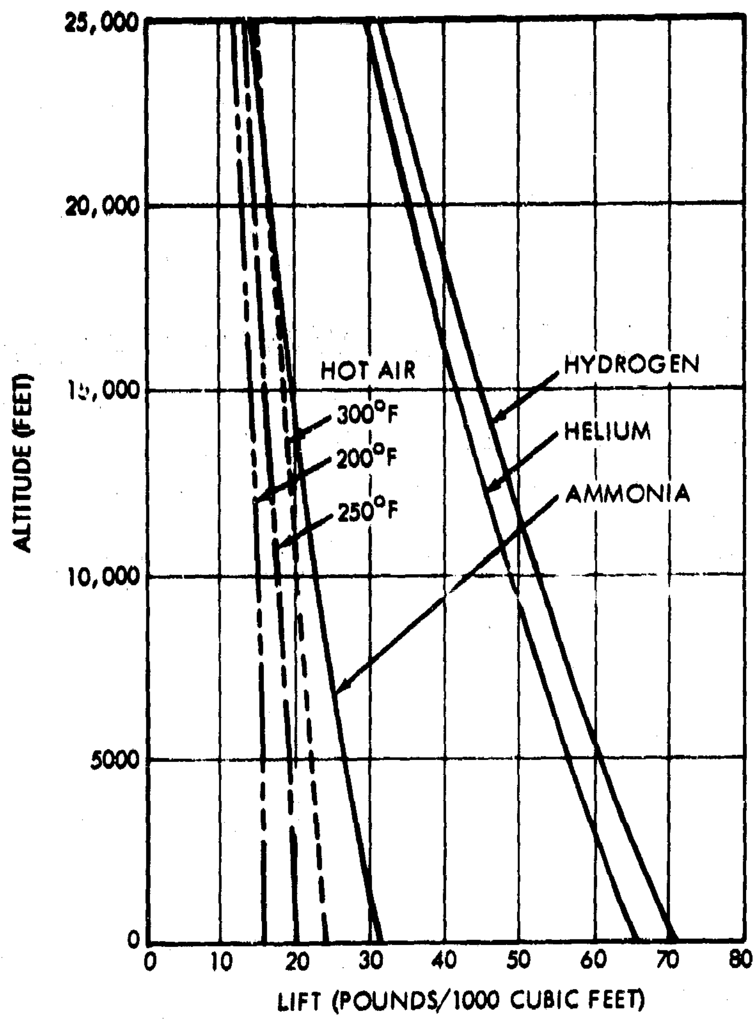


Figure 24. Specific Lift of Gases at Various Altitudes

With the exception of helium and hot air, all of these gases are flammable. The latter three gases have been used primarily in sport ballooning, because of their low cost. Hydrogen and helium are the primary choices for serious work, with hot air having intriguing advantages for certain applications. Hydrogen is less expensive than helium, has 8 percent greater lift per cubic foot, and is highly flammable. It can be generated on the site from a variety of processes, frequently utilizing available local water. Helium ordinarily is only available in steel cylinders under pressure of 1800 psi or less. Both hydrogen and helium can be stored or transported cryogenically. The normal boiling point at one atmosphere pressure is -452.1°F for helium and -423.0°F for hydrogen.

Hydrogen or helium usually permeates a given elastomer or plastic film by closely similar amounts. In addition to loss of gas outward, there will be infusion inward of air and water vapor to degrade the lifting gas. Seams, valves, and other details can frequently contribute greater gas loss over a period of time than diffusion through the envelope surface. Total "tightness" of the envelope is usually of considerable interest in a balloon to be operated, or at least inflated, over a lengthy period of time. Occasional "topping-off" will be necessary, and eventually repurification or replacement of the gas will be required when purity is too low.

The hot-air balloon is strictly a "superheat" balloon and does not have the tightness requirements of the gas-inflated envelope. It is ordinarily an unpressurized balloon, being open at the base for the admission of burner heat. Modern hot-air envelopes are tightly woven, single-ply, calendered, and uncoated. Pressurized natural shape hot-air balloons are available, and pressurized aerodynamically shaped hot-air balloons are possible.

The hot-air balloon has the unique capability of ready, low-cost inflation without stored or generated lifting gases. Fuel may be carried aloft, or for prolonged periods of operation, a fuel line may be connected to a ground supply and the burner controlled either at the balloon or from the ground.

4. BALLOON DISPLACEMENT

An empirical method of determining the necessary balloon size for a given payload, altitude, and design wind requirement is given in Table X. The payload is taken as the basic reference, and several tries may be necessary before a suitable balloon size is determined.

Balloon weights (step 4 in Table X) are based on a 50 to 60 knot capability for blimp or Vee-Balloon hulls. The natural shape hot-air balloon would not normally be operated beyond 20-knot winds.

Tether strengths (step 5 in Table X) will reflect design wind requirements, except again in the case of the hot-air natural shape. Here a 20-knot design limit is assumed.

A typical problem for sizing a necessary ballonet volume for altitude capability is given below. The problem also covers maximum rate of ascent and descent as limited by a given exhaust valve or blower capability, respectively.

(1) Calculation of Required Ballonet Volume

At 5000 feet above MSL, the expansion ratio is $1.16 = \rho_0/\rho_{5000}$. (Expansion ratio is reciprocal of density ratio.) Assuming a balloon volume ($\forall$) of 100,000 cu ft.

$$1.16 = \frac{100,000}{100,000 - v_{bal}}$$

where v_{bal} is the ballonet volume in cu ft.

Solving for the above,

v_{bal} = 13,830 cu ft (No allowance for superheat.)

Table X. Method of Calculating Balloon Size

Step	Aerodynamic Shapes, Gas-Filled: Single-Hull (blimp)	Aerodynamic Shapes, Gas-Filled: Double-Hull (Vee-Balloon)	Natural Shape, Hot-Air (See Note 3)
1. Divide payload weight, W_P, by helium lift capability at design altitude for determination of reference volume. c_f = (0.067 lb/cu ft) (ρ_{alt}/ρ_0), where ρ_{alt}/ρ_0 is from Reference 6. For hot-air balloons, use c_f = 0.20 lb/cu ft without altitude effects.	$\frac{W_P}{(w_a - w_g)_{alt}} = \mathcal{V}_{ref}$	$\frac{W_P}{(w_a - w_g)_{alt}} = \mathcal{V}_{ref}$	$\frac{W_P}{0.020} = \mathcal{V}_{ref}$
2. Determine factor for design altitude (altitude in feet).	$K = 0.0239\ (\text{altitude})^{0.6}$	$K = 0.070 \left(\frac{\text{altitude}}{1000}\right)^2 + 3.28$	$K = 0.00027\ (\text{altitude}) + 1.50$
3. Find required balloon volume, $\mathcal{V} = (\mathcal{V}_{ref})K$.	$\mathcal{V} = (\mathcal{V}_{ref})K$	$\mathcal{V} = (\mathcal{V}_{ref})K$	$\mathcal{V} = (\mathcal{V}_{ref})K$ Diameter $= 1.27 \sqrt[3]{\mathcal{V}}$
4. Find required balloon weight, W_B (including rigging).	For $\mathcal{V}$ = 1,500 thru 20,000 cu ft, $W_B = 0.0237\mathcal{V} + 25$ For $\mathcal{V}$ = 20,000 thru 500,000 cu ft, $W_B = 0.0175\mathcal{V} + 150$	$W_B = 0.307(\mathcal{V})^{0.77} - 30$	For diameter of 30 thru 100 ft, $W_B = 0.00056\ (\text{dia})^3 - 11$ For diameter of 100 thru 300 ft, $W_B = 0.0443\ (\text{dia})^{2.3} - 1210$
5. Find required tether strength for design wind: P_T = strength required in pounds (includes FS = 2.0) n = number of identical balloons in vertical stack V_K = design wind speed in knots $\mathcal{V}$ = balloon volume in cubic feet	$P_T = 0.00274\ (V_K)^2 n(\mathcal{V})^{2/3}$	$P_T = 0.0034(V_K)^2 n(\mathcal{V})^{2/3}$	For 20-knot wind (maximum) $P_T = 0.025\ (\text{dia})^3$
6. Select rope or tether from Section V. Multiply weight/foot by distance from launch altitude to design altitude. (See Note 2.)	Tether weight, W_T, = (design altitude - launch altitude) (tether wt/ft)		
7. Fuel and tankage weight, W_F (hot-air balloons only)	Not applicable	Not applicable	$W_F = 0.0392\ (\text{dia})^2$ per hour of operation
8. Total weight = $W_P + W_B + W_T + (W_F)$	Gross weight = $W_P + W_B + W_T$	Gross weight = $W_P + W_B + W_T$	Gross weight = $W_P + W_B + W_T + (W_F)$ (hr operation)
9. Gross static lift = $\mathcal{V}\ (w_a - w_g)_{alt}$. This value should exceed gross weight by 5 to 10 percent. If over or under size, assume new $\mathcal{V}$ (refer to step 3).			

NOTES:
1. Individual variations in design payload, wind, altitude, (fuel time for hot-air balloons) may necessitate several resizings.
2. Wind will require additional length (and weight) of tether to be supported when balloon is at design altitude. A procedure for calculating this effect is given in Reference 7. The calculation of the ultimate lift capability of aerodynamic shapes will require precise knowledge of dynamic lift and drag characteristics of specific balloons. (See Figure 75 in Appendix I.)
3. Hot-air (natural shape) balloons are normally considered only capable of static lift. Additional static lift can be accomplished by operating at greater temperature differentials.

(2) Calculation of Maximum Rate of Ascent

Assuming that the ballonet exhaust valve can permit 1500 cfm at the pressure differential desired, the rate of ascent and the time to altitude can be calculated as follows:

$$\text{Rate of ascent} = \frac{1500}{13,830}\,(5000) = 542 \text{ fpm}$$

$$\text{Time to altitude} = \frac{5000}{542} = 9.2 \text{ minutes}$$

(3) Calculation of Maximum Rate of Descent

Assuming a blower capability of 400 cfm, the rate of descent and the time from altitude can be calculated as follows:

$$\text{Rate of descent} = \frac{400}{13,830}\,(5000) = 144 \text{ fpm}$$

$$\text{Time from altitude} = \frac{5000}{144} = 34.6 \text{ minutes}$$

All aerostatic calculations are based on coefficients (such as C_L and C_D) based on a reference area of $V^{2/3}$. In aeronautical expressions comparable coefficients are based on wing plan-form area in square feet.

Care should be taken in comparing such coefficients from European and U.S. sources, or from different periods of time. Frequently they are not based on common dimensional references. Coefficients for spheres and other geometric bodies may be based on maximum cross-sectional area or some other reference area.

Helium unit lift ($w_a - w_g$) at 100 percent purity is 0.065988 lb/ft^3 at standard atmospheric sea-level conditions of 59°F and 29.92 in. Hg. Lift at any altitude is 0.065988 times the altitude density ratio. With gases other than helium, multiply the helium lift by the ratio given in Table IX.

5. COMPUTING HELIUM REQUIREMENTS

The appropriate balloon size and necessary helium gas to lift a required total balloon system weight to a required altitude can be determined from Table X. Unit helium lift ($c_\ell = w_a - w_g$) can be obtained from Table XXXI in Appendix I or by reference to the U.S. Standard Atmosphere (Reference 6).

Figure 25 presents a graphical representation of the final equations in Appendix I. Where standard conditions do not prevail, unit lift can be determined from Figure 25 when pressure, temperature, and gas purity are specified. To determine unit lift from the graph, proceed as follows.

(1) Enter the figure horizontally from the left at specified barometric pressure.

(2) Travel horizontally to the right until diagonal temperature line is intercepted.

(3) Drop vertically from this point to intercept with diagonal purity line.

(4) Travel horizontally to unit lift value at right.

This unit lift is with the assumption that both ambient air and gas are at the specified conditions of temperature and pressure.

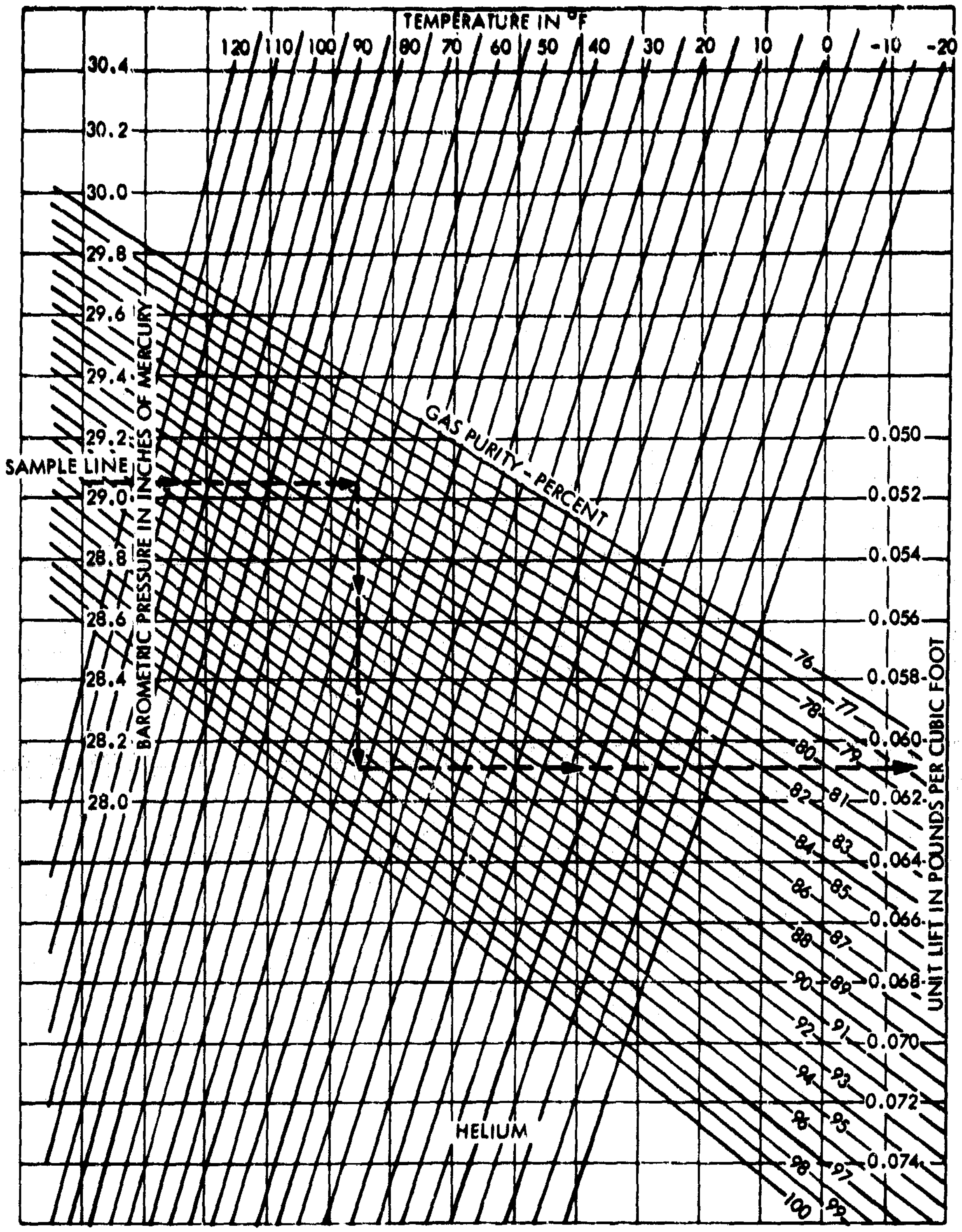


Figure 25. Lift of Dry Helium Versus Temperature, Pressure, and Purity

6. COMPUTING HYDROGEN REQUIREMENTS

Table X is set up for sizing balloons inflated with helium. Inflation with hydrogen can be covered by adjusting the lift of helium by the appropriate factor of 1.08 as given in Table IX.

Figure 26 is a graphical representation of the final equations of Appendix I, based on the weight differential of air and hydrogen. Use of the graph is identical with the procedure for using the graph for helium (Figure 25).

7. COMPUTING HOT AIR REQUIREMENTS

Hot-air balloon envelopes are considered to be operated at constant volume and, since open at the base, at ambient pressure (unless deliberately superpressured by blower).

Ambient air density varies with altitude as a result of both temperature and pressure effects. The internal heated air also varies in density with temperature and pressure. Since pressure is assumed equal, buoyant lift can be expressed as:

$$L = \forall (w_a) \left(1 - \frac{T_a}{T_b}\right) \qquad (1)$$

where

$\forall$ is the balloon volume (ft^3)

w_a is the weight of ambient air (lb/ft^3)

T_a is the absolute temperature of ambient air

T_b is the average absolute temperature within the balloon

In actual practice the gas within the balloon includes combustion products, but the weight discrepancy from pure air is negligible.

Figure 27 is a graphical representation of Equation 1 for sea-level standard conditions of the ambient air. It is a plot of the increase in specific lift with increase in balloon internal temperature, T_b.

Figure 28 indicates the trend of specific lift with altitude, with T_b maintained at a constant 250^oF.

Figure 29 shows the gross lift of envelopes of various diameters, at several altitudes, for a constant internal temperature, T_b, of 250^oF.

Figure 30 indicates the adverse effect of higher ambient temperatures on the lift capability the Raven S-50 balloon, a 60,900 cubic foot balloon. Other sizes can be ratioed as a function of volume.

Figure 31 is a presentation of the "dimpling limit" of the S-50 balloon. With heat alone, the wind velocity of dimpling on the windward side is a function of temperature differential, $T_b - T_a$. As can be seen, the addition of a blower to superpressure the balloon can eliminate dimpling as a consideration. The inherent instability of the balloon shape then alone determines the maximum wind capability.

The typical temperature distribution within a hot-air envelope and throughout the surface area is shown in Figure 32.

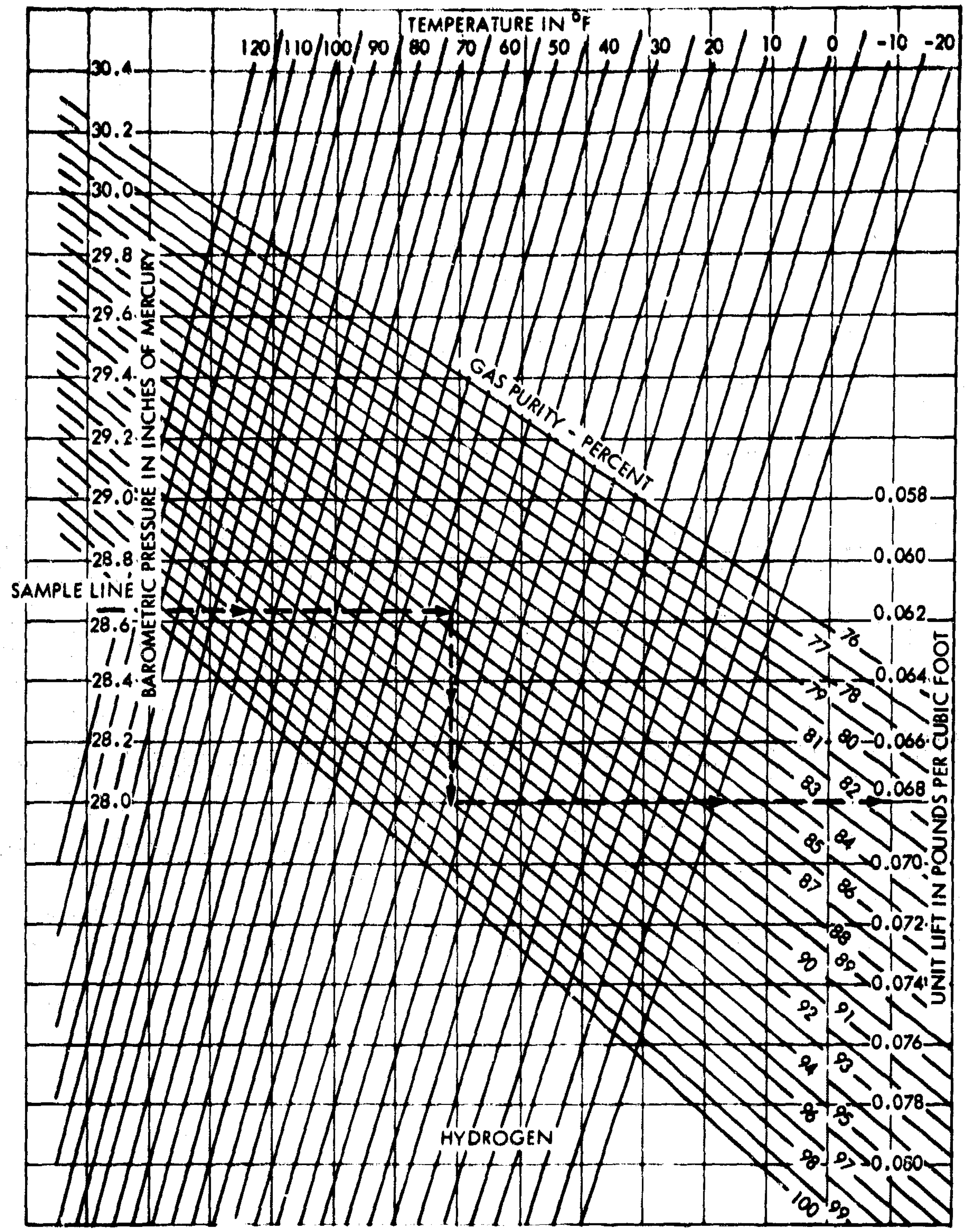


Figure 26. Lift of Dry Hydrogen Versus Temperature, Pressure, and Purity

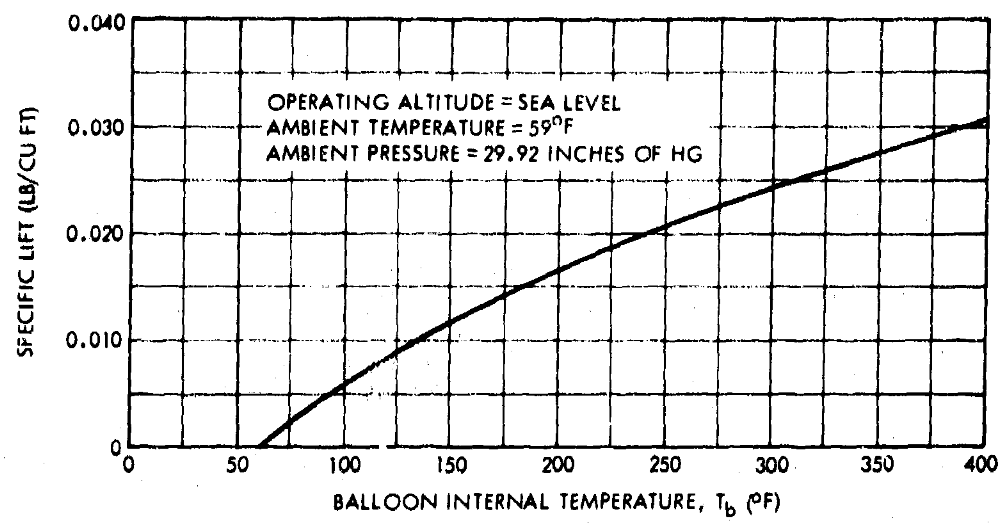


Figure 27. Specific Lift Versus Balloon Internal Temperature

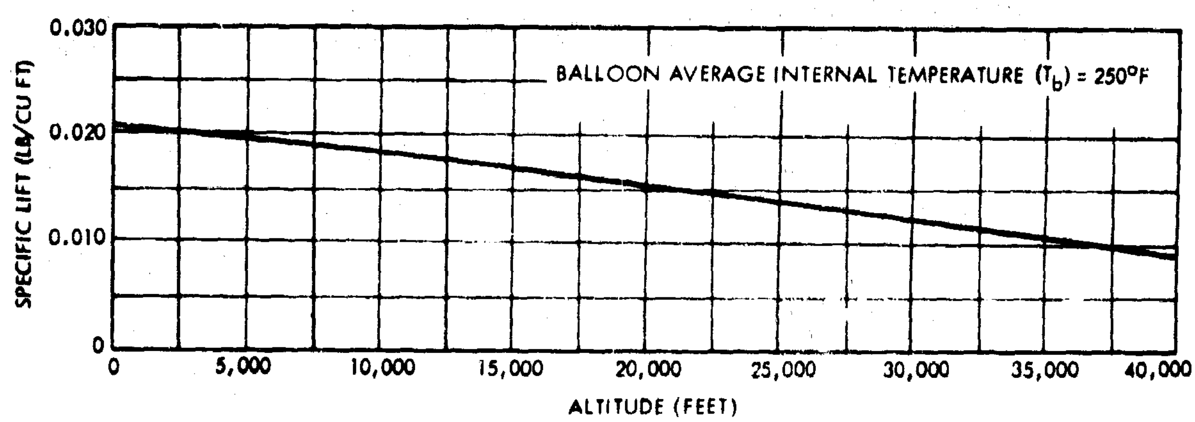


Figure 28. Specific Lift Versus Altitude - Constant Balloon Temperature

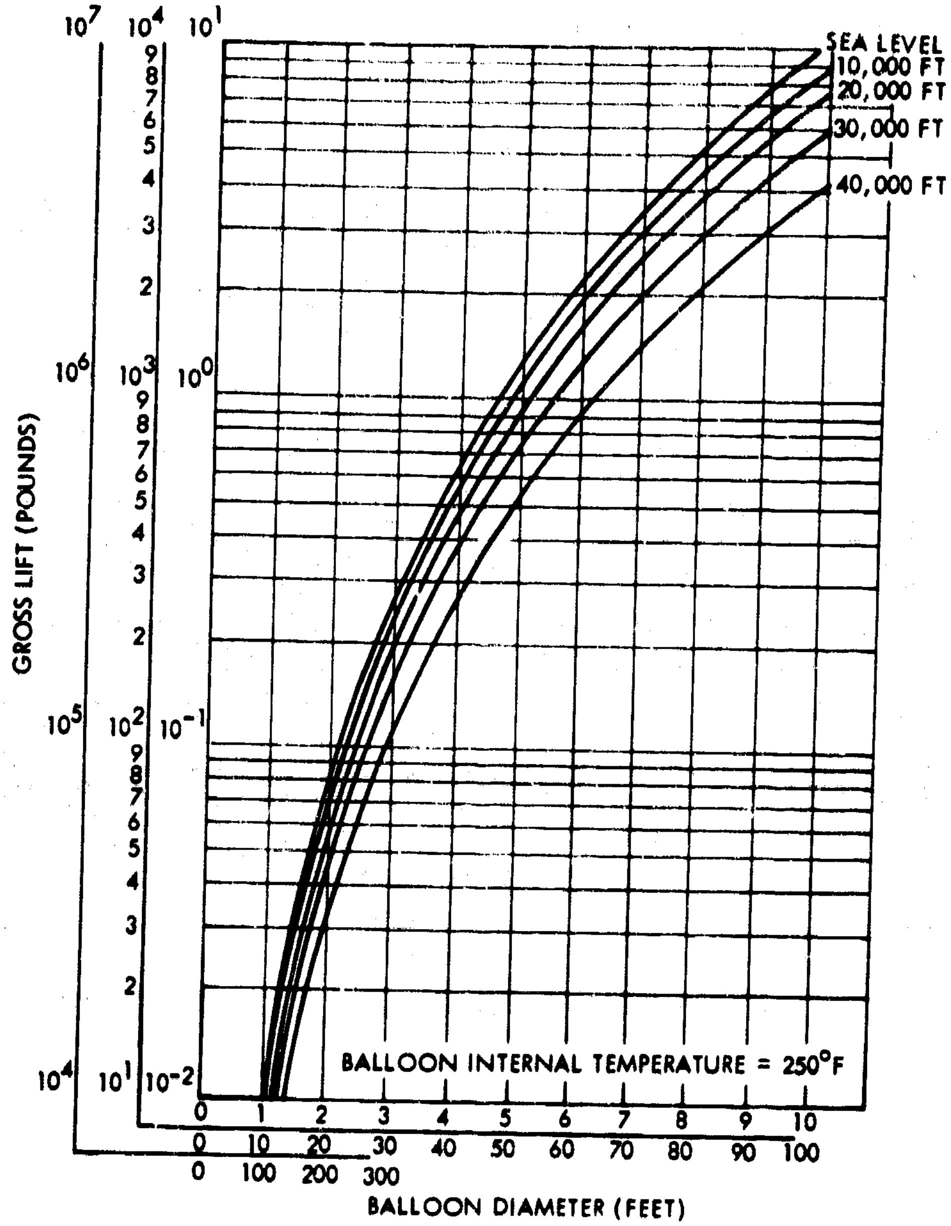


Figure 29. Gross Lift Versus Diameter for Hot-Air Balloon

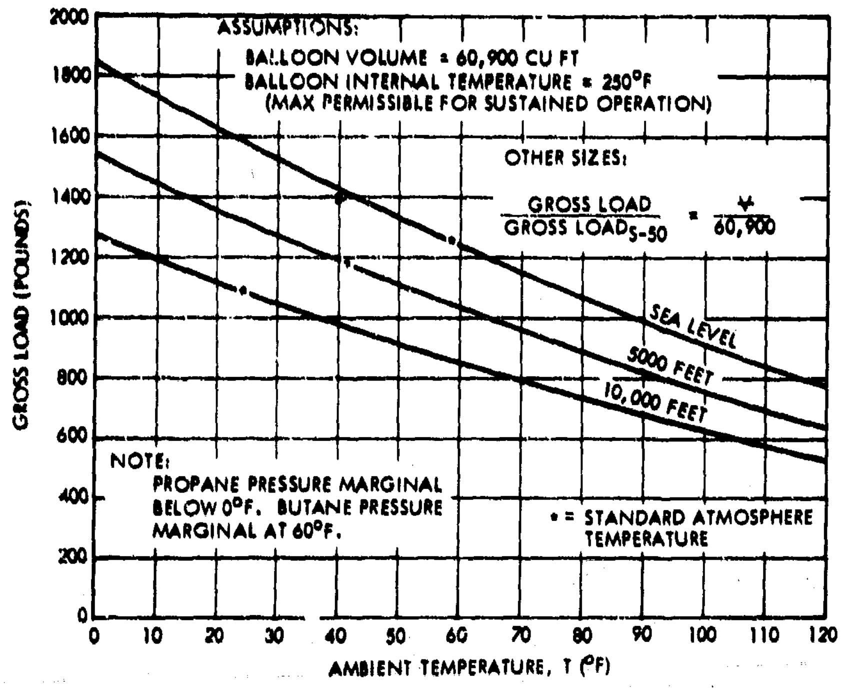


Figure 30. Maximum Authorized Operating Limits for Raven S-50 Balloon

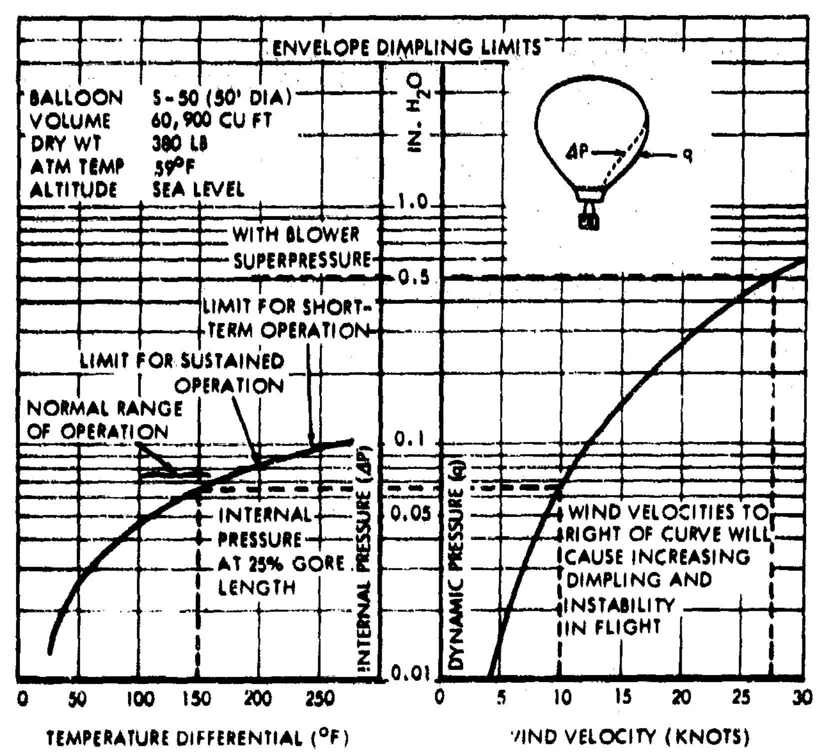


Figure 31. Hot-Air Balloon Envelope Dimpling Limits

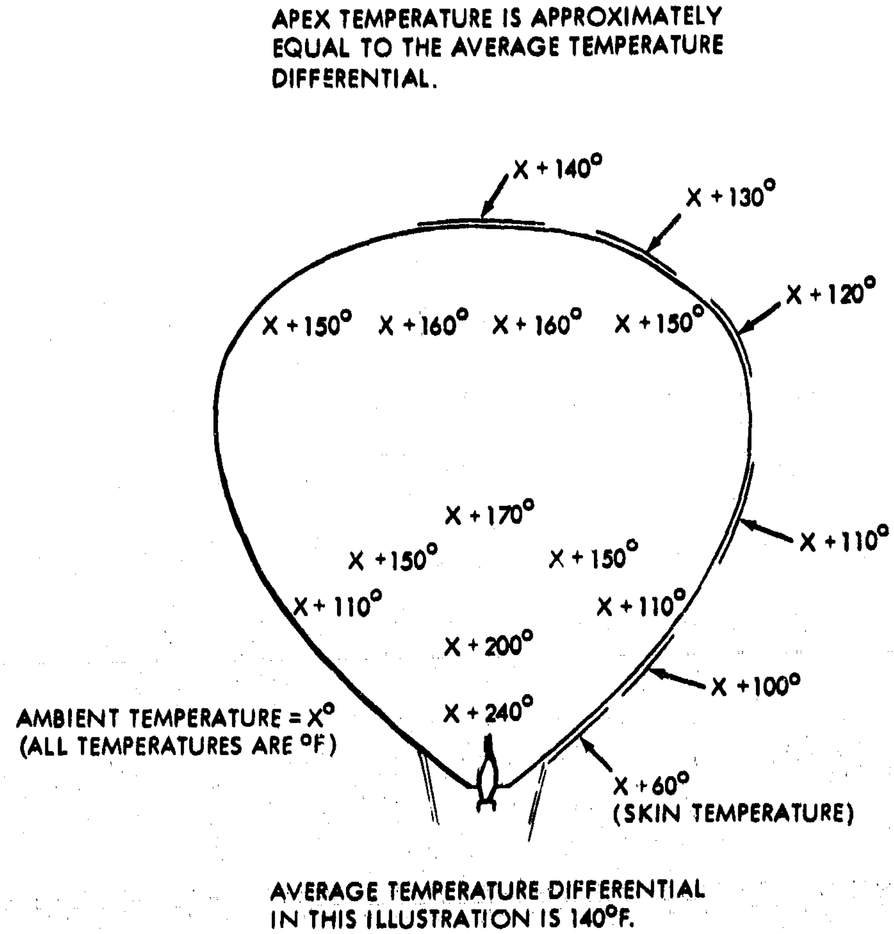


Figure 32. Internal and Skin Temperature Profile of Hot-Air Balloon

8. HELIUM REPURIFICATION

Helium can become contaminated in a balloon by leaks in the envelope and by a phenomenon called diffusion and infusion. (Refer to Section III.) The resulting contamination progressively causes loss of lift. When sufficient gas is involved, a repurification plant may be required.

At the writing of this handbook, Goodyear Aerospace Corporation of Akron, Ohio, is building a two-ton unit that will become one part of a maintenance semi-trailer. Previous to this time a unit of about six tons was required to do approximately the same repurification. The specifications for the two-ton repurification unit are as follows:

(1) Model: Goodyear 1800-G

(2) Dimensions: 103" long x 30" wide x 90" high

(3) Weight: Approximately 4000 pounds

(4) Voltage: 120/240, 60 cycle, 3 phase

(5) Peak demand power: 25 kilowatts

(6) Performance: Not less than 30 standard cubic feet per minute. Operated with minimum of attention.

(7) Freon gas: R12

The following instruments are built into the unit:

(1) Dewpointer: Parametrics Inc. Hygrometer, Model 1000

(2) Helium Purity Indicator: Beckman Instruments Therma-Bridge Analyzer, Model TBA3. 0 to 3 percent range impurities (air in helium). Samples both input and output helium gas.

The names of other companies that manufacture helium repurification plants of various capacities are listed below.

Air Products & Chemicals Inc.
Allentown, Pennsylvania

Air Reduction Co., Inc.
Murray Hill, New Jersey

Electron Technology Inc
Kearny, New Jersey

Gardner Cryogenics Corp
Bethlehem, Pennsylvania

Gas Equipment Engineering Corp
Milford, Connecticut

Linde Corporation
New York, New York

Arthur D. Little Corp
Division 500
Cambridge, Massachusetts

9. HELIUM COMPRESSOR, ELECTRICAL DRIVEN

The compressor (Figure 33) is a five-stage, radial-flow, air-cooled, electrical-driven unit with a 4000-psi output and an inlet pressure of not less than 50 psi. The compressor is normally used to transfer helium from commercial or Air Force helium bottles to a 25-foot discharge hose with the following fitting: 0.5625-18 UNF-3B per MS28740-6 (AN818-6 nut) with protective cover. The hose is normally connected to a 4000-pound bottle (see Figure 34). The motor is 208 volts ac, 400 cycle, 3 phase. The motor draws 75 amps under normal load (locked rotor 321 amps maximum) and is thermally protected against overload. The helium compressor is manufactured by Walter Kidde and Co., Inc, Belleville, New Jersey. The drawing for this compressor is 893342 Rev P.

10. HYDROGEN PROBLEMS

When mixed with air in the proportions from 4 to 74 percent purity, hydrogen forms a flammable mixture. The explosiveness of a hydrogen fire frequently makes the determination of the initial source of ignition impossible.

The natural buildup of electrical potential between pieces of equipment, various materials, and even personnel have been the causes of ignition. The flow of hydrogen from the compressed state (in storage bottles) to the lower atmospheric pressure in the presence of air can create static electrical charges resulting in self-ignition of the flowing gas. During the initial inflation of a balloon, small amounts of air are normally within the interior of the envelope. The initial rapid movement of the inflowing gas has sometimes initiated a destructive fire. Once the hydrogen-air mixture in an envelope or similar enclosure reaches 74 percent purity, the mixture of itself is no longer flammable. However, small leaks in equipment readily provide an explosive possibility if presented with any source of ignition. Some of the innocuous sources of a random spark are ferrous tools, ferrous nails in shoes, and the friction of one fabric against another.

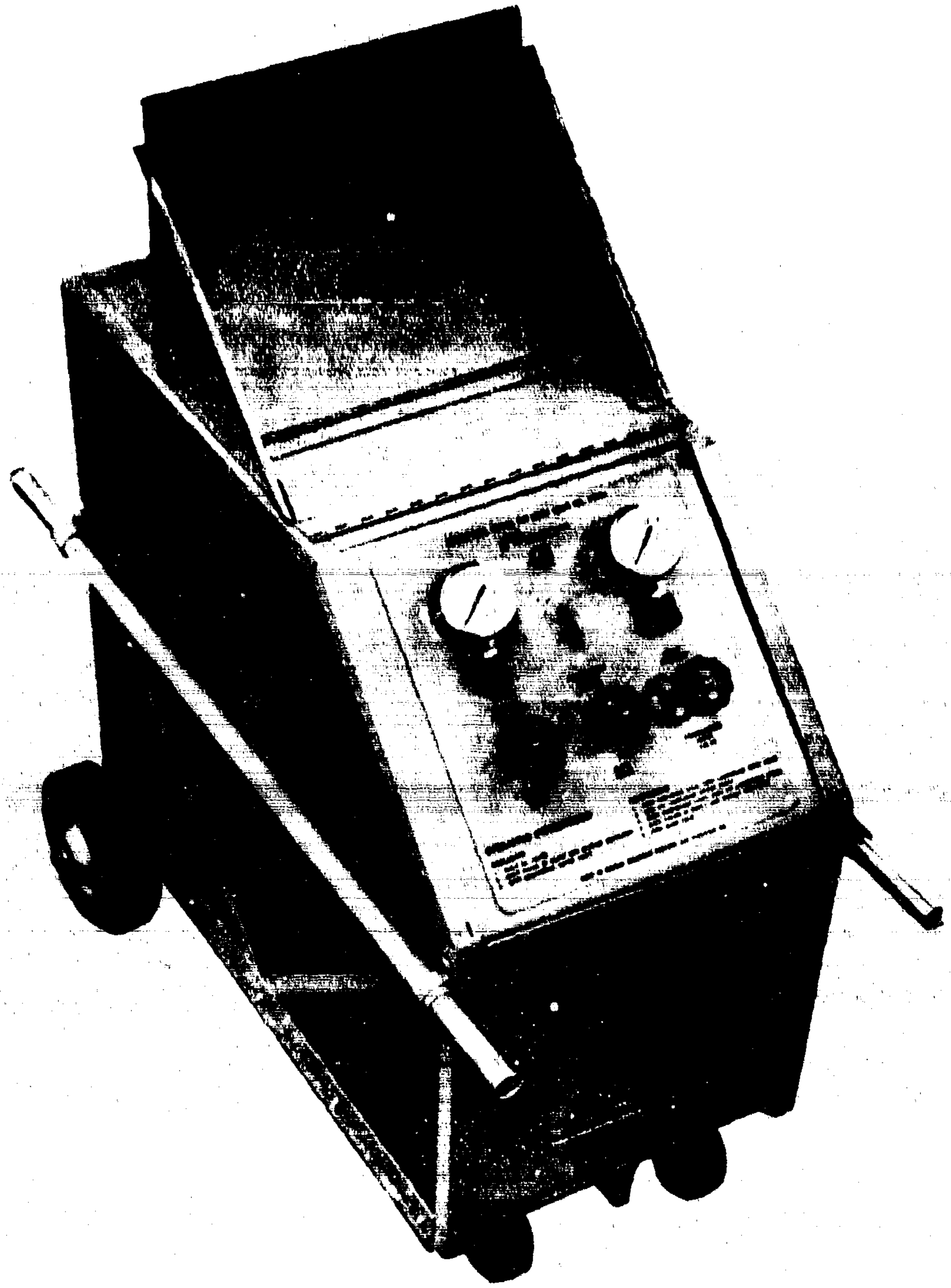


Photo supplied by Robert Fulton Co.

Figure 33. Electrical-Driven Helium Compressor

Photo supplied by Robert Fulton Co.

Figure 34. Air-Dropped Inflation Gear Kit for 750 Cubic Foot Balloon

In-flight hydrogen hazards are lightning or heavy electrical discharges through the balloon equipment and the occasionally necessary valving of gas to descend or to deflate an envelope.

Inflation area fire hazards can be reduced by heavy wetting down of a concrete floor just prior to inflation, in addition to the normal grounding procedures.

11. HYDROGEN GENERATION

Hydrogen is normally produced in almost a pure state, as repurification is far too costly compared with the initial generation process. Hydrogen purchased commercially is normally the by-product of some prime manufacturing process, such as from an alkali plant. When hydrogen production is the prime output, during wartime or in the field, the basic process is the decomposition of water into its two basic elements, either directly or indirectly.

The simplest and most direct method is to pass electrical current through water solutions, which is called the electrolytic process. Another direct method is to separate the hydrogen from the oxygen of water in the form of steam which is further superheated while in contact with hot iron, which is called the iron-contact process. Early French balloons were inflated with this process. The indirect methods are represented by the chemical reactions of certain metals and alloys immersed in strong caustic solutions such as aluminum or ferrosilicon in sodium hydroxide. The last process is normally called the silicon process.

During the American Civil War, hydrogen was generated by the vitriol process, better known as the acid-metal process (see Figure 35). The generator wagon was lined with some material to make it acid-resistant, and the wagon box partially filled with iron filings. A solution of sulfuric acid and water was dripped onto the filings, with the resulting gas passing through gum tubes to a box of cooling water. The gas bubbled up through the water and was piped to a

Figure 35. Hydrogen Generated by the Acid-Metal Process During the American Civil War

second box. The second box contained unslaked lime which acted as a drier before the hydrogen gas of about 98 percent purity was piped to the balloon being inflated. Zinc was also used as the base metal in some acid-metal units during this era.

During World War I, hydrogen gas generation in the field had been accomplished by the use of the ferrosilicon-caustic soda method, the hydrogen being produced at atmospheric pressure. The period between the two world wars saw very little progress in hydrogen generation systems.

When World War II started, the original plan was to inflate barrage balloons with helium. Due to the large amount of lifting gas required and the need for helium in man-carrying airships, hydrogen was finally used in most tethered balloons. The method of field-producing hydrogen gas in the first war was abandoned for a series of modern gas-producing systems.

During World War II, large fixed-base hydrogen plants were employed in areas where large numbers of balloons were flown and where heavy gas bottles could be moved short distances. The permanent plants were usually electrolytic hydrogen-oxygen generating plants, each with a daily capacity of 300,000 cubic feet of hydrogen. Practice has shown that a balloon barrage uses gas at the rate of 250 percent per month of original inflation capacity.

In addition to the varied commercial ways of producing hydrogen, three field systems are presently available as called out by military specifications. They are (1) Generator, Hydrogen and Carbon Dioxide, Menthol-Water Type, Low Pressure, Motor Driven, Semitrailer Mounted With Dolly, MIL-G-10157A; (2) Generator, Hydrogen, ML-539/TM under MIL-G-27369A; and (3) Generator, Hydrogen, ML-303 under MIL-G-11127B (EL). These three systems are described in the following paragraphs.

For the first system, the hydrogen and carbon dioxide gas-generating plant consists of a complete semitrailer mounted assembly for continuously forming a gas mixture of hydrogen and carbon dioxide by cracking methanol and steam in presence of a catalyst, and successively separating the gases by scrubbing the mixture with a monoethanolamine solution, purifying the hydrogen and carbon dioxide respectively, and liquefying the carbon dioxide for filling shipping containers. The plant has a continuous output capacity of not less than 4,000 cubic feet per hour of actual free hydrogen containing less than 2 percent by volume of heavier gases, and not less than 156 pounds per hour of carbon dioxide in liquid form, which shall have a purity of not less than 99.0 percent by volume before liquefying.

The rated capacity is obtained while using not more than 19 gallons of burner fuel oil per hour. The complete semitrailer mounted plant with dolly weighs not more than 41,000 pounds, and the maximum height does not exceed 11 feet.

Unless otherwise stated in contract or order, a separate skid-mounted, portable, diesel-driven, 60-kw generator set is required as a power source for plant equipment.

The second is a controlled process system which produces a hydrogen and nitrogen gas mixture by a steady flow process through a retort in which an endothermic, platinum catalyzed dissociation of anhydrous ammonia occurs. The energy for the heat of dissociation of the ammonia shall be supplied to the retort by the combustion gases of an oil burner.

The ML-539/TM consists of the necessary parts, assemblies, instrumentation, and accessories. The overall weight of the ML-539/TM, without accessories, does not exceed 900 pounds.

The ML-539/TM produces a consistent composition gas mixture of three parts by volume of hydrogen, one part of nitrogen, and 0.04 or less parts of ammonia from a feedstock of liquid anhydrous ammonia. Ammonia conforms to 0-A-445.

The equipment delivers product gas at any preset flow rate between 60 and 400 standard cubic feet per hour.

The third system, Hydrogen Generator ML-303/TM, is a portable, manually operated generator for generating hydrogen gas in the field. (See Figure 36.) The hydrogen is generated by the reaction of water on calcium hydride in charge containers attached to the generator by interrupted threads. A punch is included with the hydrogen generator for punching out the knockouts in the top of the charge container. The weight of the complete Hydrogen Generator ML-303/TM (including punch) shall not exceed 2 pounds.

A present-day system, shown in Figure 37, is used to inflate hydrogen balloons with prepackaged charges of ML-305A/TM used in Hydrogen Generator set AN/TMQ-3.

This equipment should not be operated unless all safety precautions are followed as outlined in the operating directions packed with the generator. Serious fires could result if the directions are not followed.

When using this equipment, the two operators as well as the equipment must be at earth ground potential by using the cable personnel grounds and ground straps.

Three GI cans of cool water are required; two cans are used for one generation, and the third can is used as a stand-by. The four calcium hydride chemical charges are attached to the generator. When ready to inflate the balloon, two men hold the generator down in one of the cool water cans for 15 to 20 minutes. Additional gas is generated by merely pinching off the gas line, removing the generator from the heated water, changing the four charges, releasing the tube, and inserting the generator into another cool water can. The second can is used as a condenser to remove moisture and any harmful by-products. The unit produces 24 cubic feet per charge, or an output of 96 cubic feet, when all four charges are attached. The unit can be operated with a single charge.

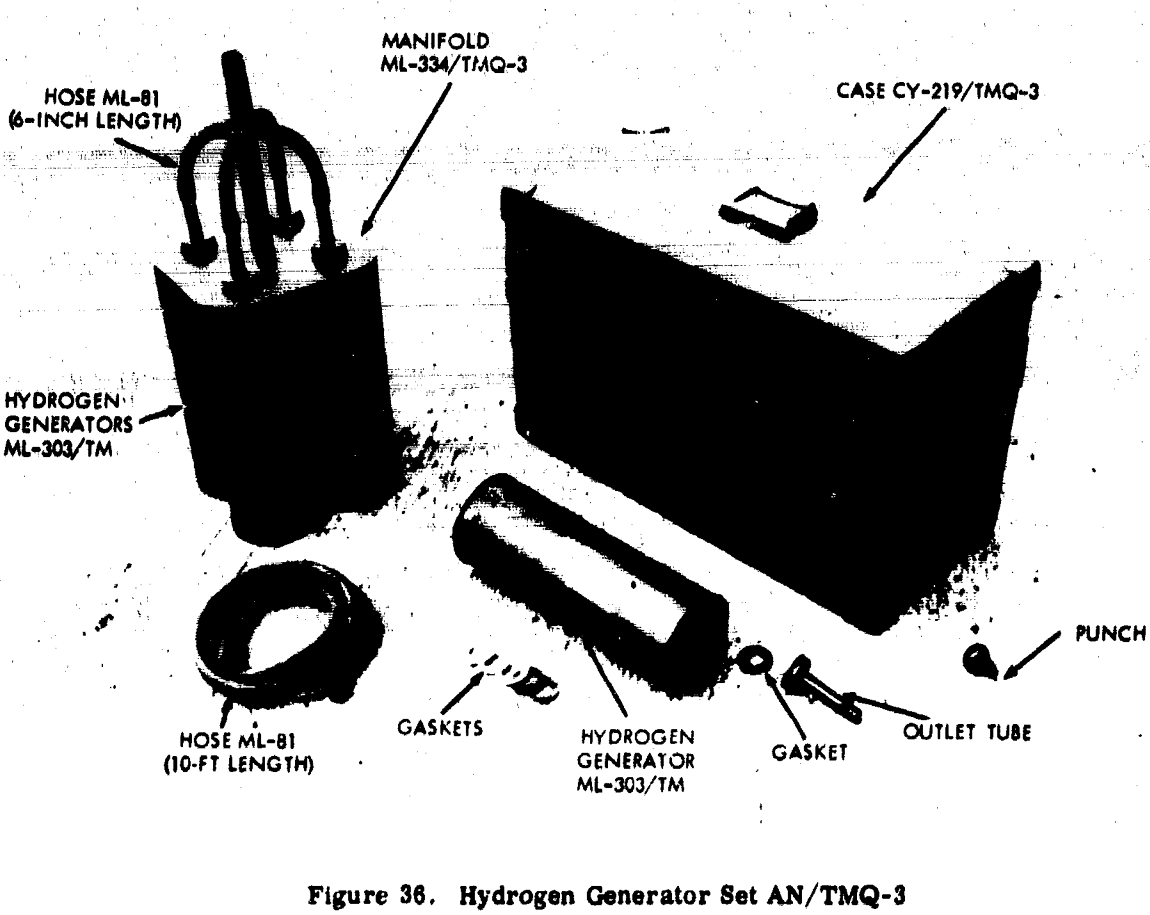


Figure 36. Hydrogen Generator Set AN/TMQ-3

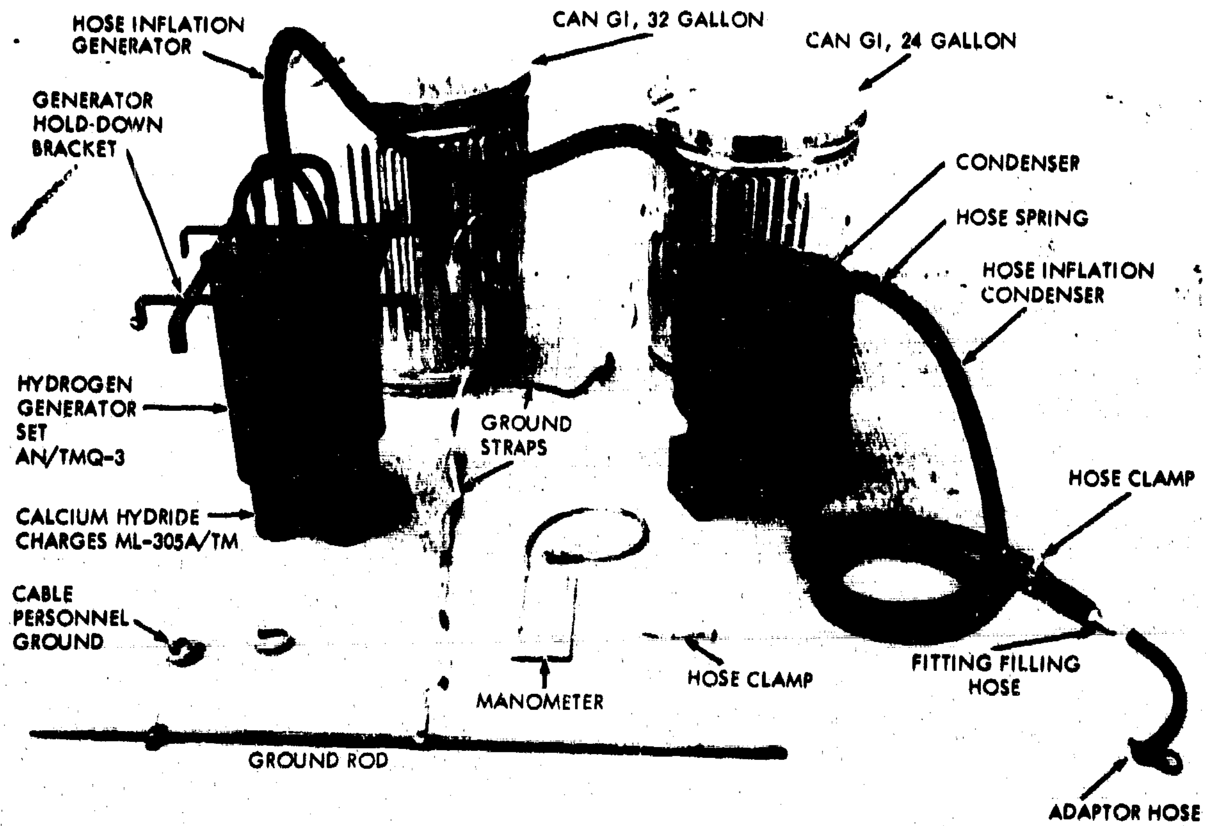


Figure 37. Hydrogen Generator Set AN/TMQ-3 Inflation Equipment

12. GENERAL SAFETY RULES FOR CYLINDERS

The following cautionary instructions are fairly standard in the use and handling of hydrogen cylinders:

(1) At all times and under all conditions, every precaution must be taken to prevent the mixture of hydrogen with air or oxygen.

(2) Smoking should not be permitted in the vicinity of hydrogen cylinders; there may be some leakage of gas due to defective valves or ruptured discs.

(3) Do not use an open flame in testing for hydrogen leaks; a soap and water solution applied to valves or piping is usually effective in locating escaping gas of any kind.

(4) Do not use a wrench on the hand wheel for opening valves, as that damages the valve seat. If valves cannot be opened by hand, they should be marked for replacement.

(5) Cylinders of hydrogen should not be discharged directly into the air; but if that is necessary, then every precaution should be taken to prevent spontaneous ignition of the hydrogen, and there should be facilities available to extinguish the flame and prevent the fire from spreading.

(6) Cylinder caps should not be left on piles of cylinders or on the ground.

(7) Cylinders must always be handled with care and not dropped or subjected to jars.

(8) Cylinders should not be exposed to fire or heat; the direct rays of the sun should be prevented by shelters over cylinders.

(9) Exceptional heating of charged cylinders by the sun usually causes losses of gas due to increased leakage and occasional rupturing of safety discs.

(10) Except when delivering gas, the cylinder valve should be kept closed and protected by the cap. This rule also applies to empty cylinders to avoid entrance of air.

(11) Hydrogen cylinders should not be stored in a confined space or room not freely ventilated. This precaution is necessary to prevent accumulation of hydrogen from leaky valves.

(12) Cylinders should not be allowed to strike on the caps during handling.

(13) Except when cylinders are being charged or discharged, the caps protecting the valves should be securely in place.

(14) When cylinders are transported by railway or motor truck, they must be held securely in place by battens or wedges to prevent movement during transit.

(15) In stacking cylinders, the valve outlet should be pointed upward to facilitate attachment of the discharge connections. Some cylinders are marked on the shoulder, indicating position of the valve outlet.

13. SAFETY RULES FOR CYLINDERS DURING BALLOON INFLATION

The safety rules applicable during inflation are as follows:

(1) Smoking or open fires should not be permitted within 150 feet of a hydrogen-filled balloon or manifold. Suitable signs should be displayed warning against smoking in the vicinity. Open fires to windward must be especially avoided.

(2) A balloon being inflated should be placed at least 75 feet from the hydrogen cylinders.

(3) Before discharging hydrogen, all cylinders should be grounded electrically to lessen danger from ignition of hydrogen; the grounding should include all manifold piping and personnel.

(4) Valves should not be opened slightly to blow out valve passages before connection to the manifold, as that frequently has caused ignition of hydrogen.

(5) The valves of high-pressure cylinders containing hydrogen should be opened slowly at first.

(6) Particular care must be taken to prevent the inflation tube or appendix from kinking or twisting, as it may be ruptured and ignite the gas.

(7) The manifold should not be moved without first closing all cylinder valves connected thereto.

(8) After discharging cylinders, the valves should be fully closed before disconnecting from the manifold and protecting caps installed.

(9) Signs of suitable size should be placed on piles of cylinders, stating whether filled or empty.

14. SAFETY RULES FOR CYLINDERS AROUND HYDROGEN PLANTS

The safety rules for cylinders being handled around hydrogen plants include the following:

(1) Before charging cylinders, inspect to determine the kind of gas remaining as residue from previous contents. In case of doubt, the residual gas should be analyzed to make certain that it is not oxygen or any other gas that would form an explosive mixture or damage balloon fabric.

(2) A noise about like a pistol shot or less in cylinders containing compressed hydrogen indicates a small quantity of oxygen, the burning of which does not generate sufficient heat to rupture the cylinder walls, but is a danger signal of importance. An increasing quantity of oxygen is sometimes produced in cylinders on account of chemical changes resulting from corrosion.

(3) Any cylinders exposed to fire or dented by rough handling must be marked as defective and retested in accordance with Interstate Commerce Commission (ICC) regulations before being used again.

(4) Before cylinders are charged, examine for dents, cracks, or damaged valves.

(5) Cylinders used for one gas should not be used for any other gas until the cylinders have been devalved and washed out per ICC regulations.

(6) If cylinders have contained such gases as oxygen or chlorine, they should be annealed in accordance with ICC regulations before being used for other gases.

(7) When cylinders are charged, the letters "MT," frequently marked in crayon on cylinders as an abbreviation for the word "empty," should be erased.

(8) Empty hydrogen cylinders to be stored 4 months or longer should be subjected to the following procedure: empty out all water that has collected in the cylinder; then purge with dried hydrogen to 50-lb pressure, three times; then fill the cylinder to about 30-lb pressure with hydrogen especially dried by passing through a drying agent to prevent deterioration of the cylinder due to rust inside. It is advisable to paint cylinders and caps before long storage.

(9) Every 5 years cylinders must be tested in accordance with specification 3A of the ICC and the date stamped on each cylinder. No cylinder should be charged with compressed gas if the date of the last test exceeds 5 years.

(10) Cylinders should be protected from weathering, and painted as required to prevent corrosion due to rust or chemical action that might diminish the thickness and strength of the walls.

SECTION V

WINCHES AND TETHERS

1. WINCHES - GENERAL DESCRIPTION

Winches for tethered balloon operations are used to raise and lower balloons to the desired altitude and make necessary operational adjustments to the balloon altitude during flight operations. Relatively inexpensive hand-operated winches may be used for small, low-altitude balloons. Power-driven winches come with a multitude of available features and can range in price from several hundred dollars to several hundred thousand dollars. Some of the features of power-driven winches for tethered balloon applications which add significantly to the cost of the winch are variable speed drives, capstan or traction drives, level wind mechanisms, and various line speed, tension, and footage measuring instruments. The winch system installation may be permanent, mobile, or portable.

Tethered balloon winches are rarely "off-the-shelf" items and are usually custom-tailored for a specific application. Many winch manufacturers have standard components from which these special winches can be assembled, thereby eliminating much of the design time and expense which would otherwise be required.

2. TYPES OF WINCH INSTALLATIONS

Permanent winch installations are used at military and civilian test sites that perform frequent balloon flights for weather and other scientific programs. Figure 38 shows Giffard's

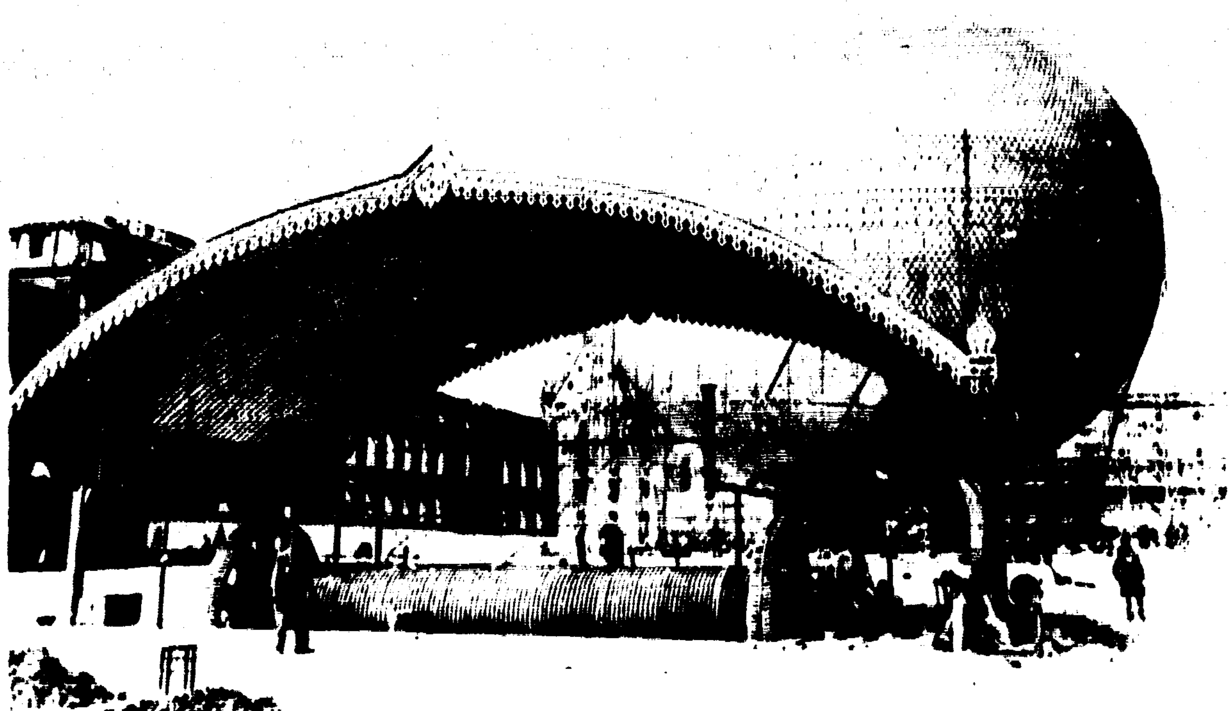


Figure 38. Giffard's Captive Balloon (25,000 Cubic Meters) and Steam Windlass, 1878 (Charles Dollfus Collection)

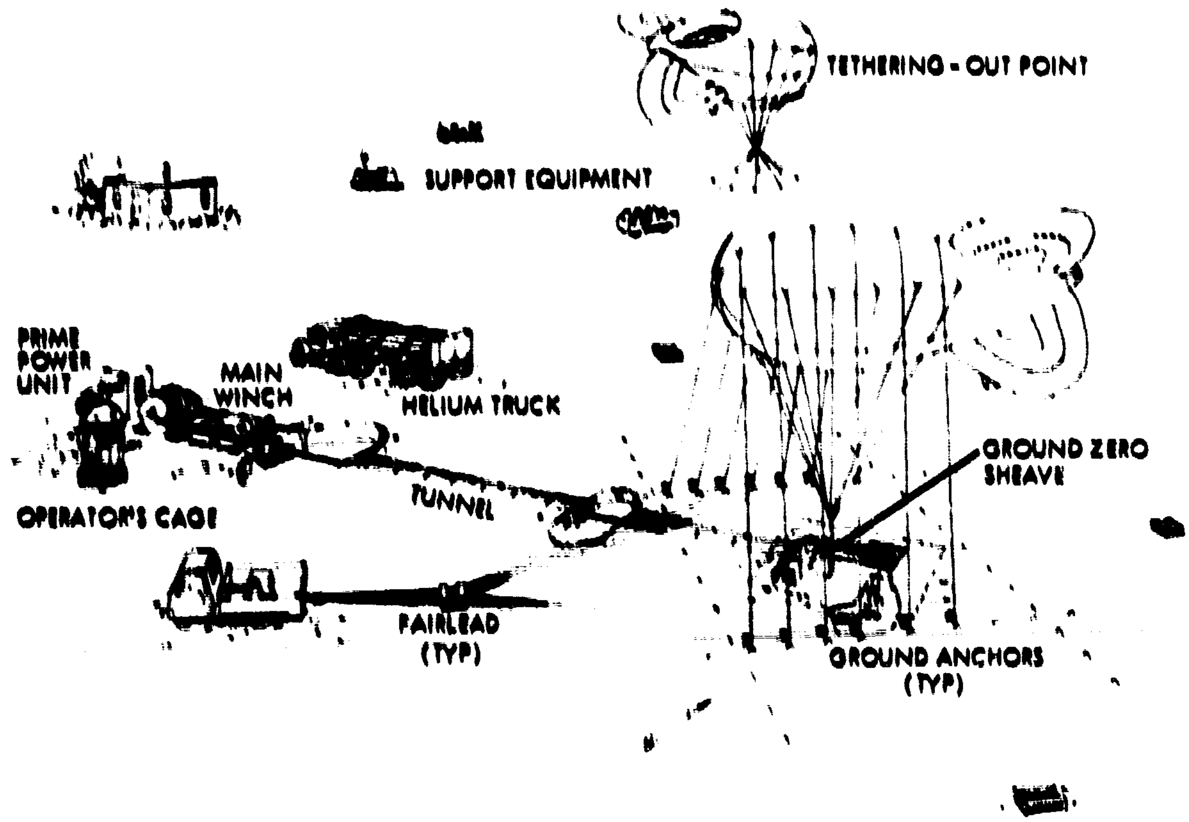


Figure 39. AFCRL Balloon Tethering Site - WSMR, New Mexico

installation in France in 1878. Locations used for tethered balloon operations are included in Appendix III and may have permanent installation winching equipment available for use, as does AFCRL at Holloman Air Force Base.

Permanent winch installations, in addition to the main tether winch, may also have auxiliary ground handling winches or an equivalent system such as the truck-pulley arrangement shown in Figure 39 to be used for bedding-down the balloon once the tether line has been completely reeled in. Such ground handling equipment is not necessary if the balloon in question is not excessively large and sufficient manpower is available.

A mobile winch is defined as one permanently attached to a wheeled or tracked vehicle, whereas a portable winch is not an integral part of a mobile vehicle but is small enough to be transportable. Figure 40 illustrates the difference between permanent, mobile, and portable winch systems. The balloons used with such mobile and portable winches are generally in the small to intermediate size category due to the obvious fact that if the balloon lift can exceed the winch system weight, some means must be provided for anchoring the winch to the ground. Tethered balloon systems, both civilian and military, for use in communication and weather station applications often require equipment capable of being airlifted or transported over rough terrain to remote areas. In such situations, the use of a portable winch becomes mandatory.

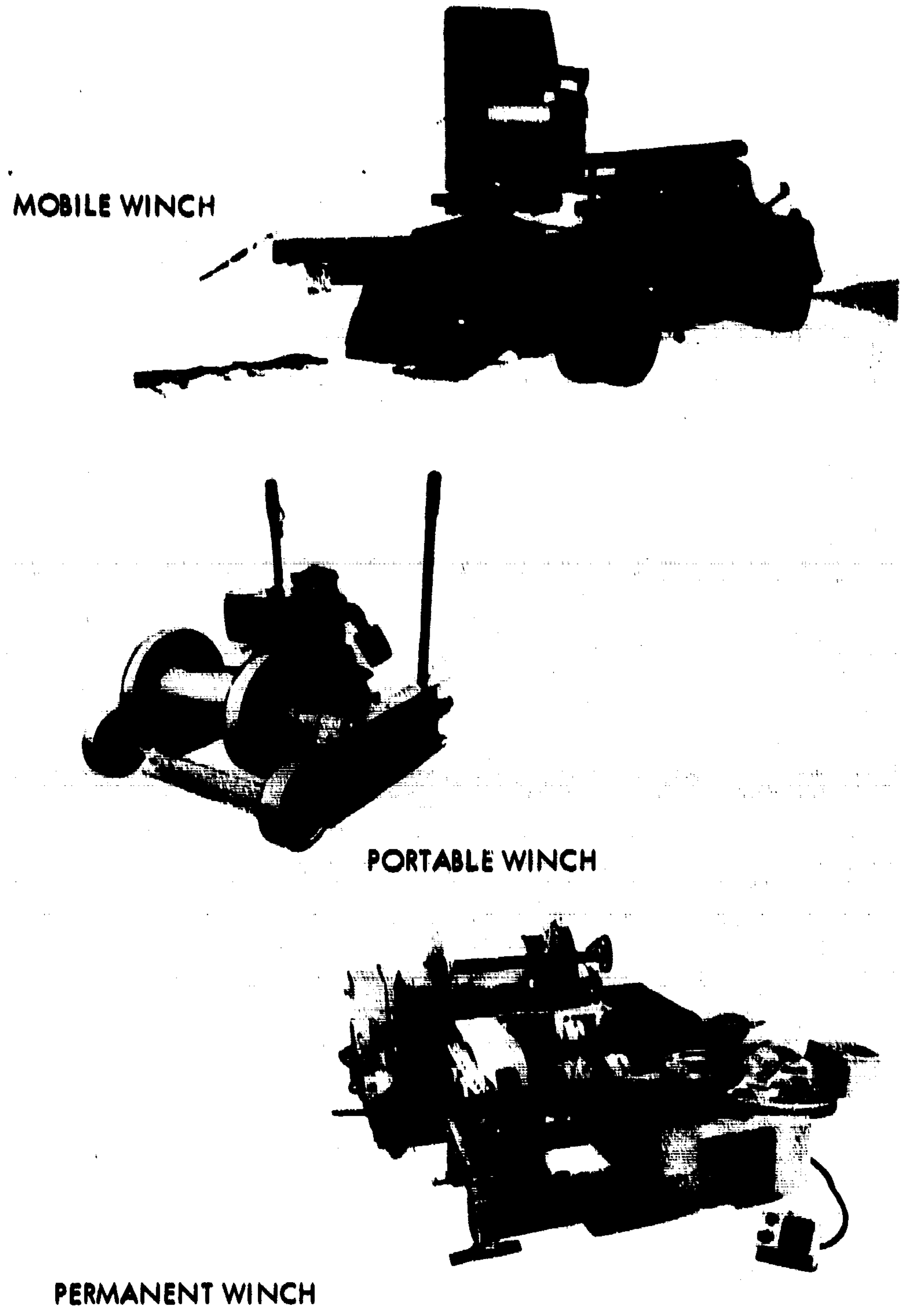


Figure 40. Types of Winch Installations

3. BASIC WINCH COMPONENTS

a. General

The basic components of a tethered balloon winch are the winch power source and drive mechanism, winch storage drum, winch capstan or traction drive, level wind mechanism, and the winch instrumentation and controls (see Figures 41 and 42).

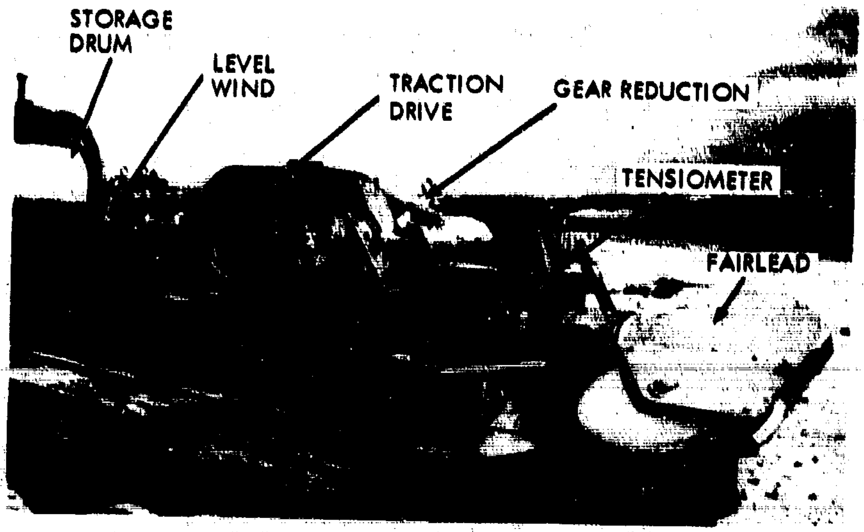


Figure 41. Basic Tethered Balloon Winch System Components

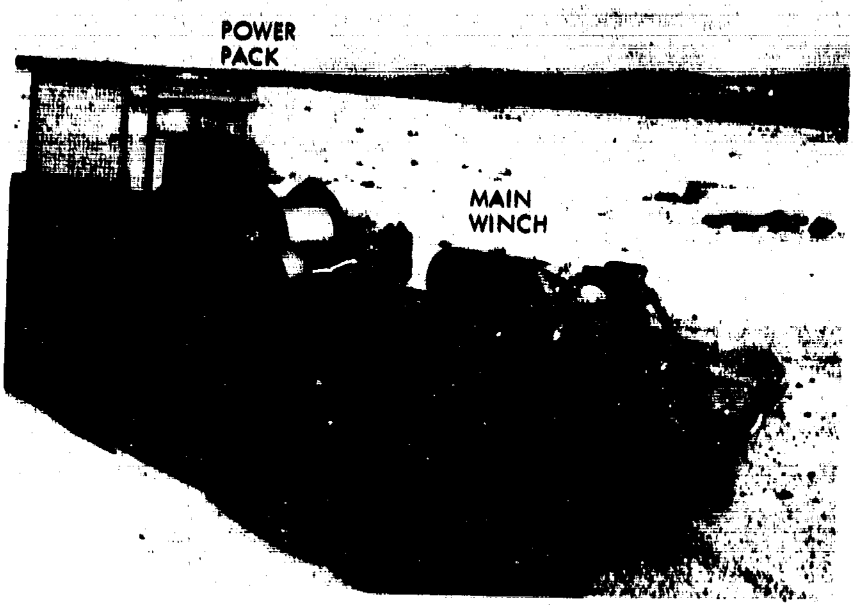


Figure 42. Largest Winch at Holloman AFB, 1968

b. Winch Power Source

The selection of the winch power source depends largely on the facilities at the intended winch site. Gasoline or diesel internal combustion engines driving electrical, hydraulic, and/or pneumatic motors have all been used as the source of motive power in winch systems. Portable and mobile winch systems are normally gasoline- or diesel-engine powered.

In selecting the actual type of power source to be used, the following percentages of the actual horsepower, with due allowance for transmission losses, should be selected so as to compensate for sudden shocks and overloads.

Steam	85%
Electric Motor	100%
Diesel Heavy (slow speed)	110%
Gasoline Multi-cylinder (heavy duty)	120%
Diesel Light (high speed)	120%
Gasoline Multi-Cylinder (high speed)	140%
Gasoline Single Cylinder (large flywheel)	150%

c. Power Transmission and Brake System

The drive shaft of the prime mover is usually connected to the winch storage drum by means of a gear train or chain and sprocket drive or some combination of the two with an appropriate clutching mechanism. Clutches currently in use can be categorized as mechanical, electrical, or hydraulic. Mechanical clutches are of two main classes - positive and friction drive. While positive clutches are usually small and uncomplicated, they cannot be engaged at high speeds and provide no protection against sudden overloads, as does the friction clutch. Electrical clutches perform the same functions as mechanical clutches, but are activated and controlled electromagnetically rather than mechanically. An electrical clutch can act as either an on-off or continuous-slip device. Hydraulic or fluid coupling clutches perform much the same function as that of the mechanical centrifugal clutch. An advantage of fluid couplings is that during starting or for other shock loadings, the clutch simply slips.

Winch brakes may be used as an on-off device or as a drag device, as is done in freewheeling during a balloon's ascent. Winch brake systems can be categorized as either mechanical or electrical. A mechanical brake is a friction device that converts kinetic energy to heat and dissipates it into the atmosphere. It can be actuated mechanically, pneumatically, hydraulically, or electrically. Electric brakes are of three basic types - magnetic particle, eddy-current, and hysteresis.

d. Winch Storage Drum

The winch storage drum (Figure 43) is used for spooling and storing the balloon tether cable and must be capable of withstanding the compressive loads exerted on it by the stored cable. The drum must be selected to facilitate storage of the maximum desired cable capacity and of sufficient strength to handle the loads involved. The storage drum core may be smooth or in some cases grooved to provide support to the cable. A significant reduction in cable life may be experienced due to the abrasive and crushing action of improperly wound tether cable. Cable crushing becomes increasingly severe with each additional layer of cable wound on the drum. The application of a high line load to a drum on which underlying cable layers were stored at low loading may cause the cable to crush through the outer layers, resulting in cable snarling and damage.

e. Storage Drum Capacities

The capacity of a given tether storage drum is calculated by the formula given in Equation 2.

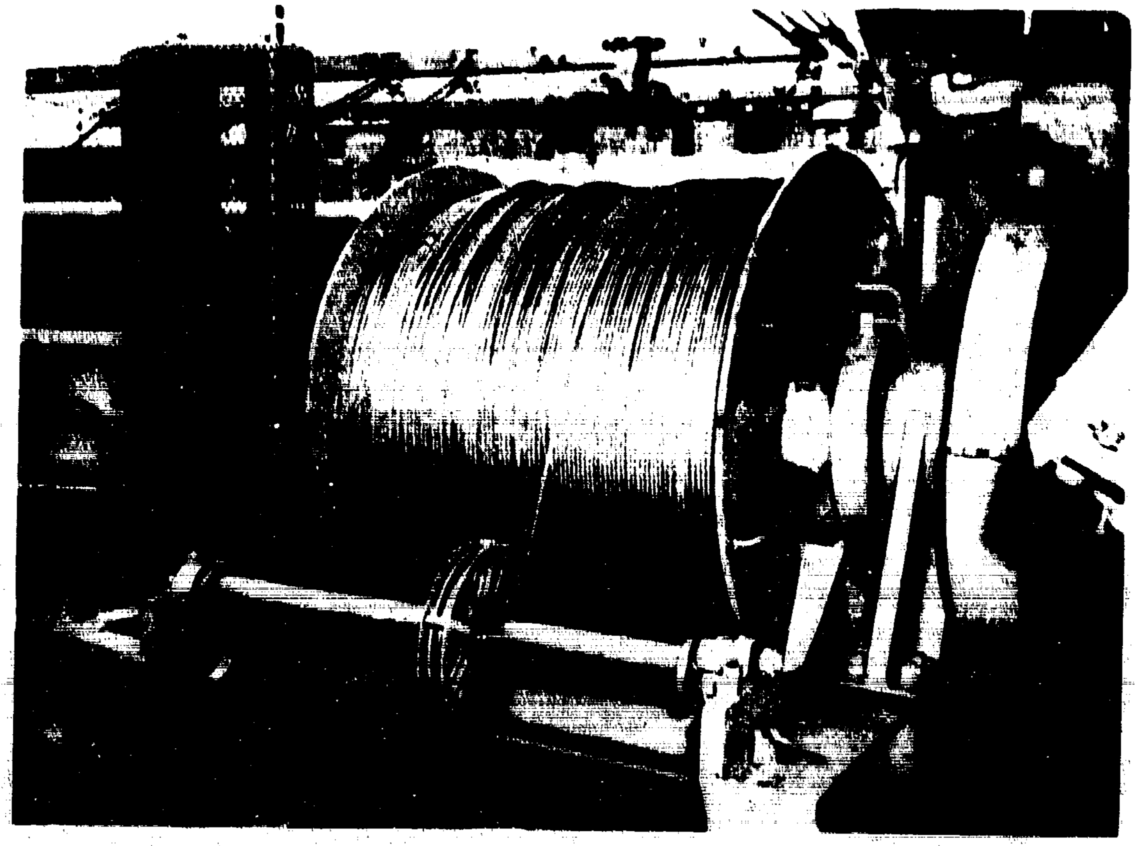


Figure 43. Winch Storage Drum

$$L = (A + D) \times A \times B \times K \qquad (2)$$

where

L = rope length (feet)

K = constant given in the list below

$A = \frac{H - D}{2} - C$ = radial distance from drum to outer layer (inches)

B = drum width (inches)

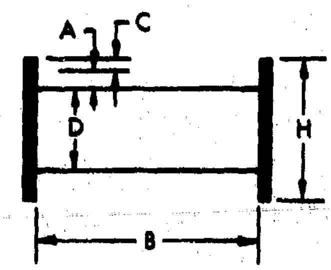
H = flange diameter (inches)

D = drum diameter (inches)

C = flange clearance (inches); distance from flange outer edge to topmost layer

Rope Dia (inches)	Constant K	Rope Dia (inches)	Constant K	Rope Dia (inches)	Constant K
1/16	49.8	1/2	0.925	1-3/8	0.127
3/32	23.4	9/16	0.741	1-1/2	0.107
1/8	13.6	5/8	0.607	1-5/8	0.0886
5/32	8.72	11/16	0.506	1-3/4	0.0770
3/16	6.14	3/4	0.428	1-7/8	0.0675
7/32	4.59	13/16	0.354	2	0.0597
1/4	3.29	7/8	0.308	2-1/8	0.0532
5/16	2.21	1	0.239	2-1/4	0.0476
3/8	1.58	1-1/8	0.191	2-3/8	0.0419
7/16	1.19	1-1/4	0.152	2-1/2	0.0380

The formula is based on uniform winding and will not give correct results if rope is wound non-uniformly on the reel. It is based on the same number of wraps of rope in each layer, which is not strictly correct, but which does not result in appreciable error unless the traverse (B) of the reel is quite small compared with the flange diameter (H). The clearance, shown in the sketch at the right, should usually be 2 inches unless fittings on ends of rope require greater clearance. The value of K allows for normal oversize of ropes.



For example: How much 1-inch rope can be wound on a drum that is 12 inches in diameter, 36 inches wide, and has flanges 40 inches in diameter, leaving a 2-inch clearance

H = 40" B = 36" D = 12" K = 0.239 C = 2"

$$A = \frac{H - D}{2} - C = \frac{40 - 12}{2} - 2 = 12 \text{ in.}$$

$$L = (A + D) \times A \times B \times K = (12 + 12) \times 12 \times 36 \times 0.239$$

$$L = 2477.95 \text{ ft}$$

f. Fleet Angle and Level Wind Mechanism

When the tether cable is led from a winching drum directly onto the fairlead, the rope is parallel to the sheave groove only when it is at one point on the drum - usually the center (see Figure 44).

As the rope moves from this point either way, an angle is created and wear starts on the side of the rope. This angle, called the fleet angle, should never be greater than 1-1/2 degrees on either side. Any greater angle creates needless wear on the sides of the rope. This holds true for either grooved or smooth drums.

This degree of fleet angle has been established by experience to give a minimum of side wear against the groove walls or against the next wrap of rope in the case of a smooth drum. A fleet angle of 1-1/2 degrees means that the fairlead should be approximately 40 feet away for each foot of drum width from the center line. If the fairlead is lined with the center of the drum and the drum is 3 feet wide, there is a foot and a half on each side and the fairlead should be 1-1/2 times 40 feet away, or 60 feet away.

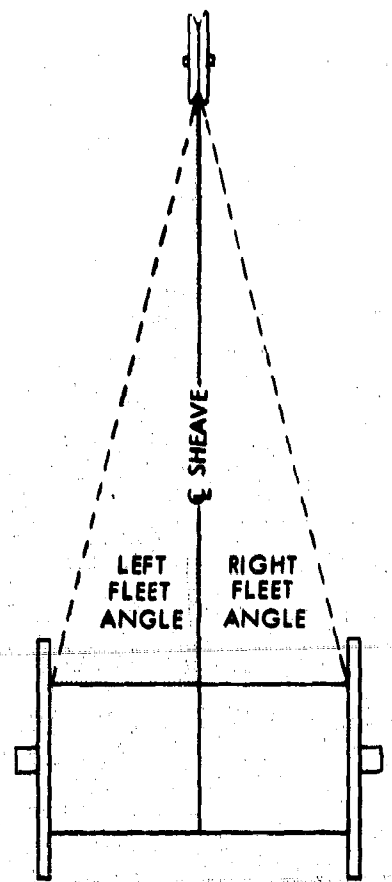


Figure 44. Fleet Angle

A level wind mechanism such as the one shown in Figure 45 can be incorporated into the winch system to lessen the possibility of an unevenly wound storage drum. However, the fleet angle between the fairlead and the translating level wind sheave must still not exceed 1-1/2 degrees.

g. Capstan or Tractive Drive

The use of a capstan or tractive drive may be required whenever high tether tension loads exist in a tether cable. If these tension loads are not relieved prior to storage on the winch drum, the resulting loads may become so high as to cause substantial crushing of both the winch storage drum and the tether cable. Capstan drives for tethered balloon systems may be either single or double drum capstans. Figure 46 shows a large tethered balloon winch system with a double capstan drive. The decrease in the tether cable load resulting from use of a capstan can be determined from Equation 3, given the high-tension cable load and other pertinent information such as the tether cable speed, cable density, cable diameter, coefficient of friction, and the cable angle of contact with the capstan drum. The equation is given as

$$(F_1 - F_2) = \left(F_1 - \frac{3w\pi d^2 v^2}{g}\right)\left(\frac{e^{f\theta} - 1}{e^{f\theta}}\right) \qquad (3)$$

where

F_1 = high tension load (lb)

F_2 = low tension load (lb)

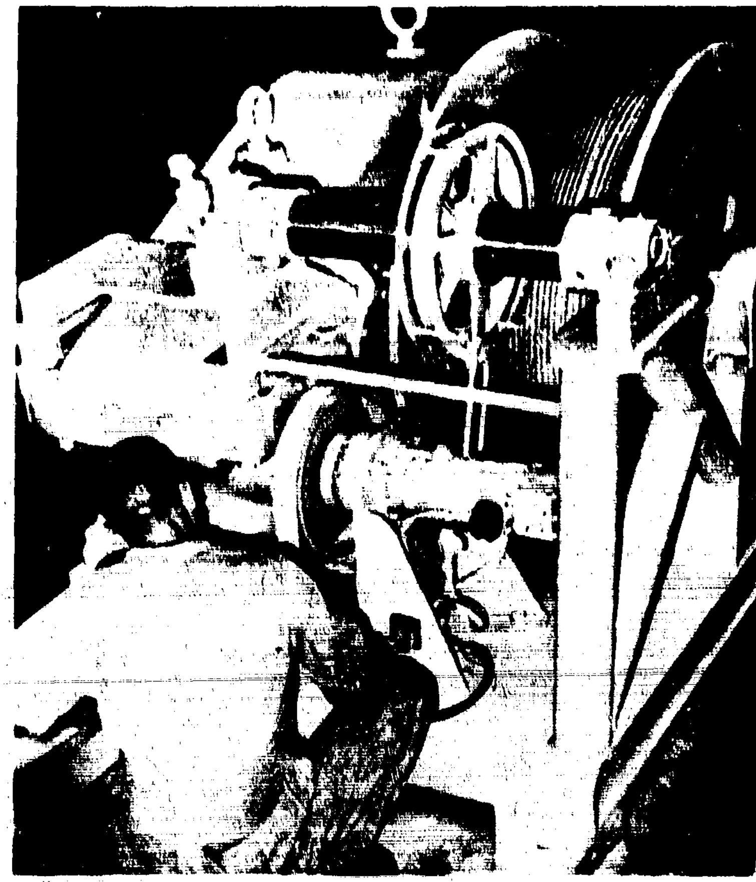


Figure 45. Level Wind Mechanism

w = weight of cable (lb/in.^{3})

d = cable diameter (in.)

v = cable speed (ft/sec)

g = acceleration of gravity = 32.2 ft/sec^2

f = cable coefficient of friction

θ = cable angle of contact with capstan (radians)

Use of a capstan also reduces the variations in the tether cable load at the winch drum by the same factor that the tether tension is reduced across the capstan. If the cable tension is 10,000 (±500) pounds and the low tension load is 200 pounds, then the variation in tether load at the winch storage drum will be 200/10,000 (±500) = ±10 pounds. Thus the use of a capstan winch arrangement also tends to reduce the power and cable tension variations occurring at the winch drum.

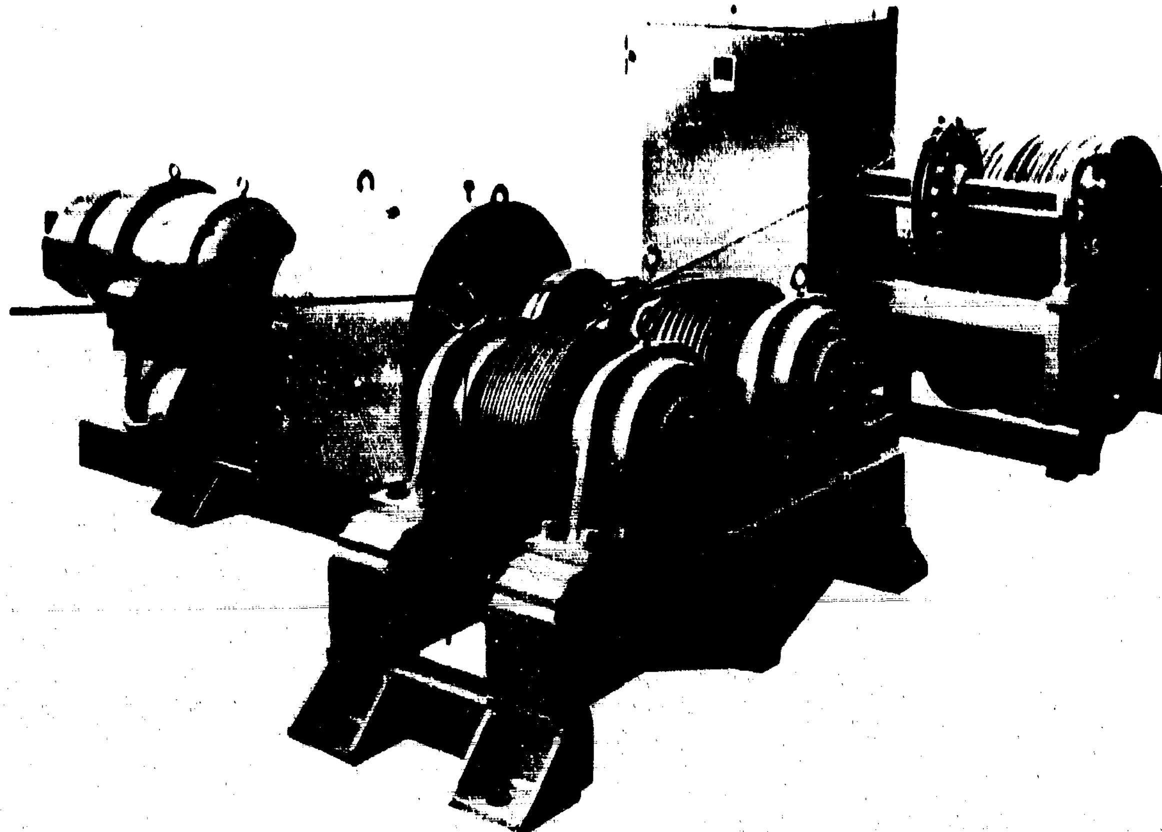


Figure 46. American Chain and Cable Co. Retrieving Winch

h. Fairleads (See Figure 47.)

Definite minimum diameters exist for rollers and sheaves used in conjunction with the winch system. Under these minimum diameters, excessive abuse is caused to the rope even if the fairlead merely guides the cable and takes no great part of the load. The sheave diameter should be at least the length of the rope lay (approximately 6 times the diameter of a six-strand cable) if the sheave is grooved, and 1-1/3 times the rope lay length if the sheave is smooth. Sheaves and rollers smaller than these minimums cause the rope to vibrate as its natural contour follows the small surface of the sheave.

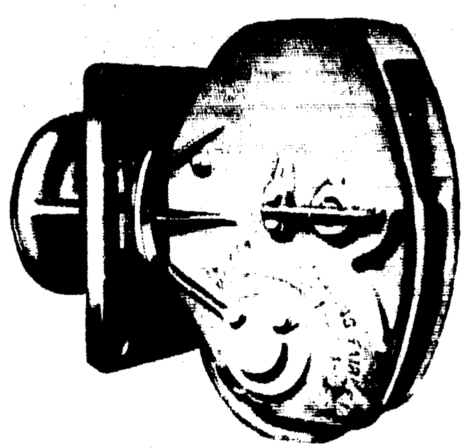


Figure 47. Fairlead

i. Winch Instrumentation and Controls

Winch instrumentation and controls for determining tether cable footage, tether cable line speed, and tether cable tension are often found desirable for tethered balloon operations. Other features such as enclosed remote or on-station control modules, slack line limit controls, automatic line take-up, audible line fail-warning devices, and fail-safe brakes are available for added convenience and safety.

4. AFCRL HOLLOMAN AFB BALLOON WINCHES

a. General

AFCRL has developed a flight test facility where tethered balloon systems can be evaluated at White Sands Missile Range, Holloman Air Force Base, New Mexico. (See Appendix III.) Several winch systems are presently located there, and a larger winch installation will be operational by the end of calendar 1969.

b. AFCRL Winch

The largest winch system presently available (see Figures 41 and 42) was built by Smith-Berger of Seattle, Washington, and is owned by AFCRL. The system is a traction-drive winch capable of handling 1/8-inch to 3/8-inch cable with static loads to 12,000 pounds. A 110-hp Ford industrial engine powers a unique hydraulic system capable of stepless speed control between 0 and 1000 fpm with controlled tension to the storage drum. It is possible to accommodate cable sizes from 0.045 to 0.400 inch by selection of traction sheave adapters and fairlead assemblies.

The inhaul and outhaul rates are as follows:

Loading	Rate
1,200 lb	1,000 fpm (in or out)
4,000 lb	300 fpm (in)
12,000 lb	Static

The storage drum capacities are as follows:

Cable Diameter	Feet
0.090"	195,000 (potential)
0.125"	104,600
0.188"	47,600
0.250"	26,250
0.375"	11,650

Figure 48 depicts the general layout. The main winch assembly, mounted on a flat-bed trailer for mobility, is positioned 100 feet from ground zero. A sheave assembly at the winch location transfers cable from winch level to ground level and enables measurements of cable tension, speed, and footage. This sheave assembly is suitable for either steel or fiberglass cable.

Figure 42 shows the overall side view of the winch, which consists of two basic units, the power pack (with heavy-duty protective cage for the operator) and the main winch assembly.

Figure 41 depicts the main winch assembly, which consists of traction drives, storage drum, level wind assembly, and necessary hydraulic motors and other components. A removable tensiometer measures tension, speed, and footage of the moving line. It is calibrated for use with 1/8-, 3/16-, 1/4-, and 3/8-inch steel cable, but is not suitable for use with fiberglass tether. Braking is by means of heavy compression springs and is fail-safe with hydraulic pressure loss.

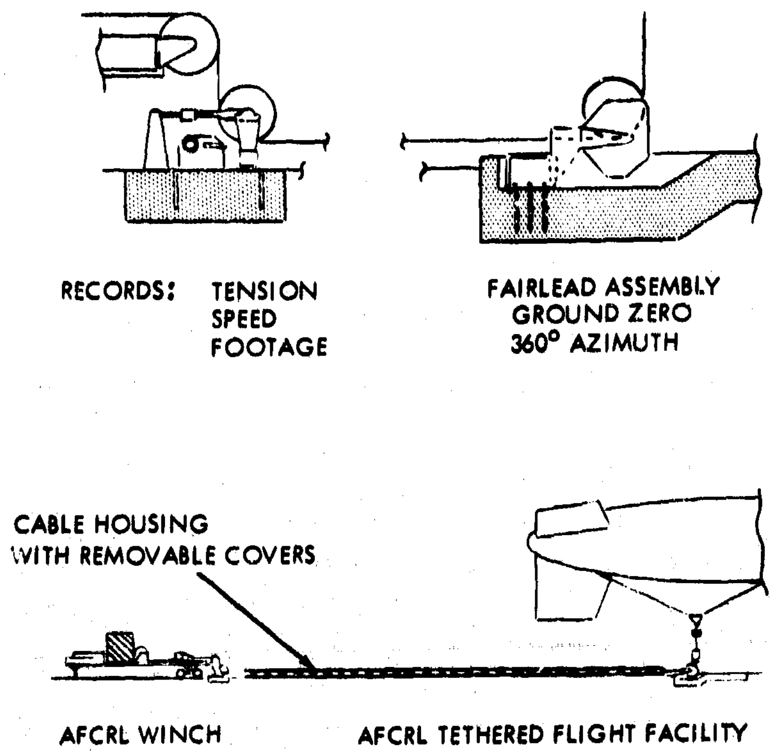


Figure 48. Tethered Site Layout for Winch Equipment

c. <u>Naval Electronics Laboratory Winch</u>

Naval Electronics Laboratory, San Diego, California, has bailed a hydraulic Smith-Berger winch to AFCRL, Holloman AFB. Figure 49 illustrates this traction-drive winch. The winch is equipped with 1/4-inch steel cable and is not adaptable to other sizes or materials, such as nylon or fiberglass.

The inhaul and outhaul rate are as follows:

Loading	Rate	
1200 lb	300 fpm	in
3400 lb	110 fpm	in
1200 lb	400 fpm	out
3400 lb	140 fpm	out

The storage drum capacity is as follows:

Cable Diameter	Feet
0.250-in. steel	14,000

The winch is powered in or out with a worm-gear drive. Friction of the worm-gear provides fail-safe holding. The winch weighs 4000 pounds and is mounted on a flat-bed trailer for mobility. The separate gasoline-driven power unit weighs 2500 pounds.

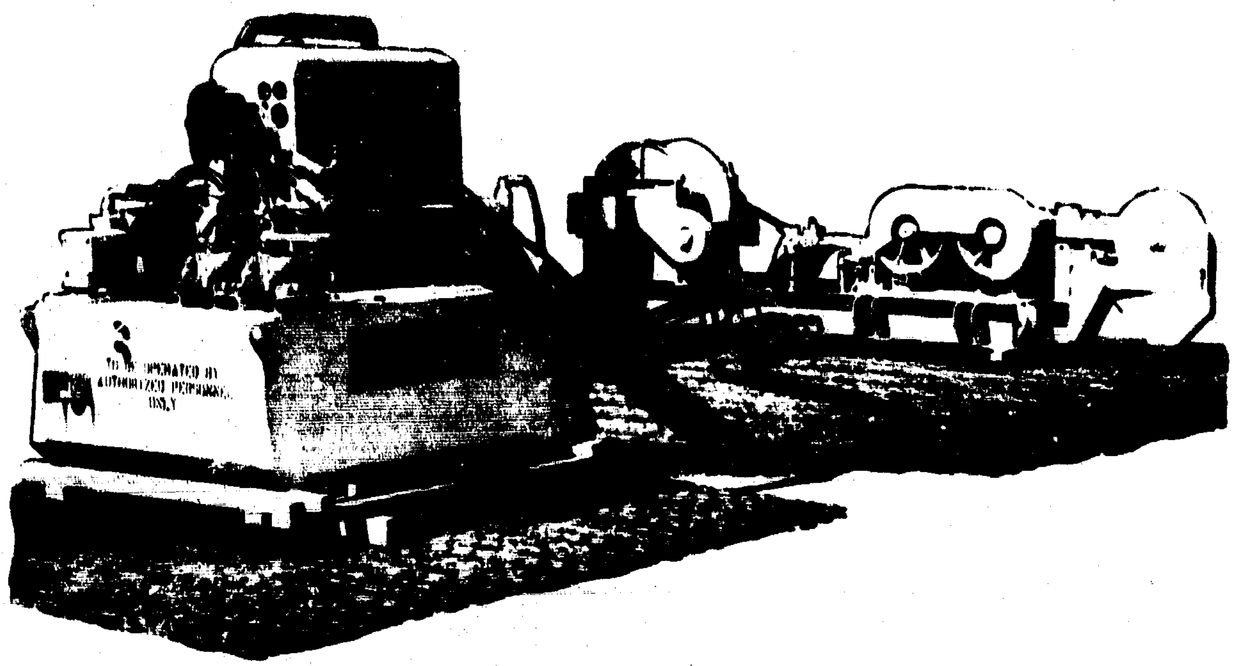


Figure 49. Smith-Berger Winch at Holloman AFB

d. Tri-Tethering Capability

Much smaller winches exist at Holloman for tri-tether accurate positioning of a balloon over a specific ground zero.

e. 1969 Capability

As of December 1969, AFCRL will have an additional operational winch system as illustrated in Figure 39. This traction-drive winch will handle cables from 3/8-inch through 3/4-inch diameter with mean sheave diameter of 30 inches. The system will be capable of stepless controlled inhaul or outhaul rates from 0 to 1000 fpm with controlled tension to the storage drum of 250 pounds (±10 percent).

The inhaul and outhaul rates will be as follows:

Loading	Rate
0 to 30,000 lbs	0 - 200 ft/minute
0 to 6,000 lbs	0 - 1000 ft/minute

Acceleration and deceleration will occur within 20 seconds with positive control.

The storage drum capacities (separate drums) will be as follows:

Cable Dia	Strength	Type	Weight	Feet
0.375"	17,000 lb	Steel	268.6 lb/1000 ft	12,000
0.625"	13,750 lb	"Nolaro"	128 lb/1000 ft	20,000
0.500" (Future capability)		"Nolaro" or fiberglass		35,000

Level wind capability will be from 3/8 to 3/4 inch in 1/16-inch increments.

Instrumentation will include the following:

(1) Footage indicator (all cable sizes) ±2% over 20,000 ft

(2) Payout and inhaul rate

(3) Tensiometer range - 200 to 12,000 pounds, ±3%. (Range of 200 to 30,000 pounds in future)

Special features will include the following:

(1) Overtension protection

(2) Audible warning of overtension or tension below 200 pounds

(3) Fail-safe braking to 30,000 pounds line pull

(4) Line-cutter

(5) Operating and flood lights

(6) Ground zero handling winch (electrical), capable of 0 to 20 fpm at 30,000 pounds

Figure 39 indicates the location of the following elements:

(1) Ground zero fairlead and handling winch position

(2) Prime mover and power transmission units (150 feet from ground zero)

(3) Operator's console with protective cage

(4) Helium supply trailer

(5) Fairleads for handling lines (four locations, 90° apart, matching pattern of ground anchors)

(6) Auxiliary tractor or truck for bedding-down

(7) Tethering-out point

5. AVAILABLE WINCHES

Engineering and performance data were obtained from many industrial sources manufacturing winch systems. Because of the vast number of winch manufacturers, only the companies that were known to have made tethered balloon winches or those whose standard winches seemed most suited to tethered balloon operations were tabulated. In gathering this information, it was observed and should be noted that winches designed for oceanographic operations can frequently be used as tethered balloon winches with only slight modification.

Figure 50 is a typical winch manufacturer's information sheet indicating the information required to design a special-purpose winch. Table XI presents the performance and size characteristics of commercially available winches. Winch manufacturers who have built tethered balloon winches in the past or have the capability of doing so on request are listed below. There are undoubtedly other manufacturers not listed here who have such design and manufacturing capability.

Adams Engineering Co.
31711 Solon Rd.
Solon, Ohio

All American Engineering Co.
Development Division
Wilmington, Delaware

Alpine Geophysical Associates Inc.
Oak Street
Norwood, New Jersey 07640

American Chain and Cable Co.
ACCO Equipment Division
1110 E. Princess St.
York, Pennsylvania 17403

American Gear and Supply Co. Inc.
5400 Cedar Crest
Houston, Texas 77017

American Hoist and Derrick Co.
57 South Robert St.
St. Paul, Minnesota

Beebe Brothers Inc.
2724 Sixth Ave. South
Seattle, Washington 98134

Clyde Iron Works Inc.
Subsidiary Republic Industrial Corp.
Duluth, Minnesota

Philip S. Dey
Farrington and Kearney Avenues
New Brunswick, New Jersey

Eness Research and Development Corp.
75 Carver Avenue
Westwood, New Jersey 07675

The Entwistle Co.
1475 Elmwood Ave.
Providence, Rhode Island 02910

Fairchild Hiller Corp.
Technical Service Div.
6501 Laffeett Ave.
Riverdale, Maryland 20840

Hyden-Murphy Equipment Co.
4501 Hiawatha Ave.
Minneapolis, Minnesota

Hydro Products
Division of Dillingham Corp.
P.O. Box 2528
San Diego, California 92112

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Ingersoll-Rand Co.
389 Columbus Ave.
Boston, Massachusetts

Joy Manufacturing Co.
Mining and Construction Div.
Dept 8, Oliver Bldg.
Pittsburgh, Pennsylvania

King Manufacturing Co.
Division of Power Tools Inc.
500 S. Hicks Rd.
Box 535
Palatine, Illinois 60067

R.G. LeTourneau Inc.
Box 2307
Longview, Texas 75601

Marine Engine Specialties Corp.
556 Broome St.
New York, New York 10013

Markey Machinery Co Inc.
79 South Horton Street
Seattle, Washington 98134

Northrop Corp.
442 Marrett Rd.
Lexington, Massachusetts 02173

Ocean Science and Engineering Inc.
Ocean Science Building
4905 Del Ray Ave.
Washington, D.C. 20014

Otis Engineering
P.O. Box 34380
Dallas, Texas 75234

Pengo Hydra-Pull Corp.
Marine Division
P.O. Box 1989
Fort Worth, Texas 76101

Sasgen Derrick Co.
3101 West Grand Ave.
Chicago, Illinois

Silent Hoist and Crane Co.
841877 63rd Street
Brooklyn, New York 11220

Skagit Corp.
P.O. Box 151
Sedro-Woolley, Washington

Smith-Berger Manufacturing Co.
3236 Sixteenth Ave. Southwest
Seattle, Washington 98134

Stanspec Corp.
4928 Schaaf Lane
Cleveland, Ohio 44131

Thern Inc.
5712 Industrial Park Rd.
Winona, Minnesota 55987

Tulsa Products Div.
Vickers Incorporated Div. of
Sperry Rand Corp.
Tulsa, Oklahoma

USM Corporation
Harmonic Drive Div.
Balch Street
Beverly, Massachusetts 01915

Value Engineering Co.
Alexandria, Virginia

Western Gear Corp.
Advance Systems Div.
2316 Jefferson Davis Highway
Arlington, Virginia

Western Scientific Services Inc.
600 Industrial Park
P.O. Box 1965
Fort Collins, Colorado 80521

1.0 GENERAL DESCRIPTION OF APPLICATION AND ASSOCIATED EQUIPMENT.

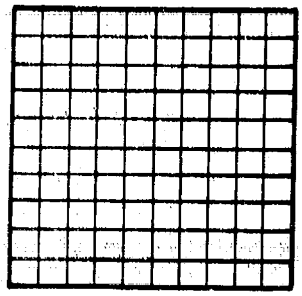
2.0 PERFORMANCE

2.1 NORMAL CABLE TENSION AND SPEED

HAUL ________ LB AT ________ FPM

PAYOUT ________ LB AT ________ FPM

USE GRAPH AT RIGHT FOR VARYING LOADS



2.2 RATED TENSION AND SPEED

HAUL ________ LB AT ________ FPM

PAYOUT ________ LB AT ________ FPM

2.3 RUNNING OVERLOAD CABLE TENSION (AT NO SPECIFIED SPEED)

HAUL ________ LB AT ________ FPM

PAYOUT ________ LB AT ________ FPM

2.4 STATIC CABLE TENSION

________ LB

3.0 DUTY CYCLE AND LIFE REQUIREMENTS

PAYOUT ________ FEET AT ________ LB, REST ________ MIN. NO. CYCLES PER DAY ________.

HAUL ________ FEET AT ________ LB, REST ________ MIN. NO. CYCLES PER YEAR ________. LIFE ________ YRS.

4.0 ENVIRONMENT

☐ MARINE - LAND BASED ☐ DESERT ☐ MARINE - SHIPBOARD ☐ ARCTIC ☐ RURAL

5.0 POWER SOURCES AVAILABLE

220 440, 60 CY. ________ ; 208V, 60 CY. ________ ; 115V D.C. ________ ;

230V D.C. ________ ; CENTRAL HYDRAULIC ________ ; OTHER ________ .

Figure 50. Data Sheet for Capstan Type Winches

6.0 CABLE

6.1 CABLE CHARACTERISTICS (LIST STEP LINE SIZES FROM LEFT TO RIGHT AS THEY ARE WOUND ONTO THE DRUM)

CABLE DIA.							
LENGTH (FEET)							
BREAKING STRENGTH							
WEIGHT/1000 FT.							
MATERIAL							
CONSTRUCTION							
OUTSIDE COATING							
MINIMUM STORAGE RADIUS							

6.2 SPECIAL SPLICES, CONNECTORS OR OTHER ITEMS WHICH MUST PASS THROUGH THE WINCH. GIVE SIZE AND PURPOSE.

7.0 SHEAVES - MINIMUM BEND RADII

SHEAVE	MINIMUM RADIUS		ANGLE OF WRAP
CAPSTAN			
OUTBOARD SHEAVES			
LEVEL WIND SHEAVE OR SINGLE ROLLERS			
LEVEL WIND WITH MULTIPLE ROLLERS 	DIA	R	

8.0 LEVEL WIND REQUIREMENTS AND DIMENSIONS NEEDED TO DETERMINE FLEET ANGLE

9.0 TENSION CONTROL REQUIREMENTS

- [ ] AUTOMATIC
- [ ] MANUALLY ADJUSTABLE OVERLOAD SETTING
- [ ] NONE

10.0 SPEED CONTROL REQUIREMENTS

- [ ] SINGLE SPEED
- [ ] STEPPED
- [ ] VARIABLE
- [ ] CONSTANT HORSEPOWER

Figure 50 - Concluded

Table XI. Available Winches (Sheet 1)

Manufacturer	Model Designation	Type of Power	Power Rating (hp)	Overall Size (inches) Length	Width	Height	Approx Weight (lb)
Adams	AT-8003-L1A	Power takeoff		86 to 96			
	AT-8003-L2A	or hyd pump-	---		---	---	---
	AT-8029-L1A	motor comb	---		---	---	---
	AT-8029-L2A		--		---	---	---
All American	64	Elec or hyd	---	54	29	29	295
	67	Elec or Hyd	---	38	29	21	111
	15C-4	Elec	2.6 or 3.6	24	24	28	144
	80C	Elec	2.6 or 3.6	40	31-1/2	30	370
	11C	Elec	---	24	22	18	165
	82	Hyd	---	38-1/4	30	23-1/2	324
	Airship remanning winch	Elec	30 hp, 3 phase	84	27	20	2,600
ACCO	Retrieving winch	Elec or Hyd	Capstan: 30 Storage: 2	---	---	---	---
	Adjusting winch	Elec	30	---	---	---	---
	Balloon winch	Elec	Capstan: 35 - 42 Storage: 7.5 - 9	240	96	84	18,400
Beebe Bros	A6B	---	---	7	11	15	19
	B6B	---	---	7	11	15	22
	L6	---	---	14	11	15	60
	L10	---	---	18	11	15	70
	H16	---	---	26	16	18	150
	H24	---	---	34	16	18	175
	1600B90	Elec	5	---	---	---	540
Clyde	Medium capacity 5,500 to 21,000	Gas or diesel	21 to 237	---	---	---	2,300 to 14,400
	Medium capacity 5,500 to 21,000	Elec	15 to 200	---	---	---	2,600 to 10,500
Hyden-Murphy	American Hoist 50-B	Gas or elec	36	67-1/2	53-5/16	47-1/2	1,125
	American Hoist 70-B	Gas or elec	68	91-1/2	76	43	3,125
Hydro Products	HR-60	Gas	6	34-1/2	21-1/2	32	250
Ingersoll-Rand	K6UAL	Pneumatic	---	58-1/2	24	30-13/16	1,550
	K6UL	Pneumatic	---	58-1/2	24	30-13/16	1,550
Joy Mfg	DW-111 } EW-111 }	Piston Air	6.0 to 8.0	22 to 25	15-3/16	17	315 to 3[illegible]5
	DF-112 } DF-113 }	Elec	7.5 to 10.0	44 to 50	25 to 26	21 to 26	875 to 900
	G-112	Gas	8 to 15	46 to 59	23	35 to 38	825 to 935

Table XI. Available Winches (Sheet 2)

Drum Size (inches)			Cable Storage Capacity		Load Capacity (lb)	Line Speed (ft/min)	Remarks
Drum	Flange	Length	Length (ft)	Dia (in.)			
---	---	22-1/2	2,100	7/16	20,000		All models are designed for truck mounting and are primarily the same except in drum design.
---	---	28	2,500	7/16	20,000		
	Divided Drum		1,850	7/16	20,000		
	Divided Drum		1,850	7/16	20,000		
---	29	---	1,000	1/4	7,000	361 at 820 lb	Remote control. Level wind. Fail-safe brakes. Pawls.
---	---	---	1,000	1/4	6,000	260 at 2000 lb	
---	---	---	1,200	1/8	1,500	150 at 300 lb	
---	---	---	1,500	1/4	8,000	150 at 340 lb	
---	---	---	3,500	1/8	2,000	300 at 400 lb	
---	---	---	9,000	1/8	10,000	1440 at 800 lb	
---	---	---	1,350	1/4	1,500	550 at 1200 lb	Constant tension winch.
15-1/2	---	---	7,000	3/8	10,000	100 at 30 hp	Heavy duty, dual drum capstan with storage drum. Remote or on-station control. Slack line limit control. Fail-safe brakes. Automatic line take-up. Hydrostatic transmission. Infinitely variable remote speed control.
20	---	---	1,500	1/4	10,000	100 at 30 hp	
30	---	48	15,000	1/2	10,000	240 at 42 hp	
2-1/2	6-1/2	6	735	1/8	1,000		Hand-operated winches.
2-1/2	6-1/2	6	735	1/8	1,000		
4	8-1/2	6	278	1/4	4,000		
4	8-1/2	10	464	1/4	4,000		
5	12-1/2	16	716	3/8	10,000		
5	12-1/2	24	1,075	3/8	10,000		
6,6	12	12	460	3/8	1,600	90	Automatic, electric brake. Load held when power off.
10 to 20	21 to 45	20 to 32	2,600 to 3,800	3/8	5,500 to 21,000	77 to 390	Accessories available: (1) torque converter for gasoline and diesel hoists, (2) special drums, (3) automatic brakes, (4) pneumatic control devices, and (5) reversing electric motors.
10 to 20	21 to 45	20 to 32	2,600 to 3,800	3/8	5,500 to 21,000	64 to 358	
9	18	18	2,141	3/8	5,000		Friction clutches and brakes - contracting band type. Ratchet and dogs for added safety.
10	20	20	1,637	1/2	7,000		
12	16-1/4	20	3,000	1/4	800	150	Recoil-started, Briggs & Stratton, 4-cycle engine. Hand-operated drum brake. Friction clutch, free-running cable payout.
13	23-1/2	24	1,200	5/8	5,000	95	Six-cylinder, piston-type reversible motor. Heavy-duty hand-operated band brake. Disengaging clutch also available.
13	23-1/2	24	1,200	5/8	7,000	65	
6	14	5-1/2	470	5/16	1,250 to 2,000	66 to 75	Special features available: (1) remote pushbutton control and (2) automatic magnetic brakes.
11-1/8	18 to 20-3/4	9 to 13-1/8	1,500	3/8	2,000 to 2,340	125 to 150	
11-1/8	20-3/4	13-1/8	1,500	3/8	2,000 to 2,750	110 to 120	

Table XI. Available Winches (Sheet 3)

Manufacturer	Model Designation	Type of Power	Power Rating (hp)	Overall Size (inches) Length	Width	Height	Approx Weight (lb)
King	130	Gas	3.0 at 3600 rpm	25	23	23	160
	240	Gas	4.0	35	23	36	270
	260	Gas	6.0	35	23	36	280
	364	Gas	6.0	42	29	41	320
	380	Gas	8.0	42	29	41	360
	480	Gas	8.0	48	35	41	365
	490	Gas	9.0	48	35	41	398
	530	Gas	3.0	24	24	30	160
	540	Gas	4.0	24	24	30	165
	560	Gas	6.0	31	28	32	295
	568	Gas	8.0	31	28	32	315
	580	Gas	8.0	36	28	32	365
	590	Gas	9.0	36	28	32	380
	703	Elec	3.0	36	28	17	415
	705	Elec	5.0	54	31	30	1,480
	707	Elec	7.5	56	31	30	1,530
	710	Elec	10.0	60	33	34	1,575
	803	Elec	3.0	38	23	19	400
	805	Elec	5.0	38	23	19	550
	807	Elec	7.5	42	31	30	700
	810	Elec	10.0	42	31	30	1,200
	1220	Gas	10.9 at 2400 rpm	48	36	34	1,050
	1835	Gas	16.4 at 2600 rpm	48	36	35	1,350
	2560	Gas	26.5 at 2200 rpm	50	40	42	2,300
	3455	Gas	34.0 at 2000 rpm	72	52	42	2,600
	6060	Gas	53.8 at 2200 rpm	84	52	42	3,000
R.G. LeTourneau	BW-30 Balloon winch vehicle	Diesel	---	387	153	159	72,500
	W-500	Elec	---	84	44	70	8,000
Markey	DW-5980 Oceanographic	Elec	25	89	74	---	8,000
Otis Engr	82MO136	Diesel	47	80	28	49	2,400
	82MO151	Diesel	47	69	60	48	2,400
	82MO23	Diesel	52	86	72	48-1/2	3,700
	82MO222 and -223	Diesel	34	Two separate units			2,100
	Special purpose unit	Diesel	30	Two separate units			1,300
	82MO271 and -193	Diesel or hyd	80	Two separate units			---
	82MO200 and -193	Diesel or hyd	80	Two separate units			
Sasgen	SDL-15-A-8 SDL-20-A-11 SDL-17-A-11	Gas or elec	8 to 11	---	---	---	735 to 775
	SDM-26-R-20 SDM-23-R-20 SDM-20-R-20	Gas or elec	15 to 20	---	---	---	770 to 1,300
Silent Hoist	TA15C	Elec	15	---	---	---	---
	WA-30AC	Elec	30	---	---	---	---
	FHA-50AC	Elec	50	---	---	---	---
	TE15AC	Elec	15	---	---	---	---
	FHE-50AC	Elec	50	---	---	---	---
Skagit	BU-6 BU-12 BU-15 BU-16	Gas Diesel Hyd or elec	---	67 to 106	60 to 79	36 to 67	1,500 to 6,800
Smith-Berger	Ground handling	Elec	---	50	42	36	---
	Upper balloon winch	Elec	200	284	96	---	---
	Lower balloon winch	Elec	300	384	96	---	---

Table XI. Available Winches (Sheet 4)

Drum Size (inches)			Cable Storage Capacity		Load Capacity (lb)	Line Speed (ft/min)	Remarks
Drum	Flange	Length	Length (ft)	Dia (in.)			
4	12	16	1,860	1/4	300	200	All series of King hydraulic controlled hoists available with gasoline, diesel, or electric power. Band friction type brakes standard. Drive is roller chain and gear combination. Ratchet and pawl equipped.
4	12	20	1,950	1/4	400	200	
4	12	20	1,950	1/4	550	200	
4	14	18	2,700	1/4	600	200	
4	14	18	2,700	1/4	750	190	
5	16	20	4,700	1/4	725	180	
5	16	20	4,700	1/4	850	180	
4	12	16	1,950	1/4	400	160	
4	12	16	1,950	1/4	525	180	
7	13	12	1,500	1/4	600	225	
7	13	12	1,500	1/4	750	200	
7	16	12	2,400	1/4	850	200	
7	16	12	2,400	1/4	1,000	200	
7	15-1/2	12	2,200	1/4	850	100	
7	16	16	1,500	3/8	1,100	100	
7	16	16	1,500	3/8	1,700	100	
7	16	16	1,500	3/8	2,150	100	
7	16	12	1,100	3/8	1,200	50	
7	16	12	1,100	3/8	2,000	50	
7	16	12	1,100	3/8	3,200	50	
7	16	12	1,100	3/8	3,700	50	
7	16	16	1,500	3/8	2,000	130	
7	16	16	1,500	3/8	3,500	122	
10	16	16	1,200	5/8	6,000	115	
10	16	16	1,200	5/8	5,500	160	
12	24	16	1,150	5/8	6,000	233	
---	---	---	1,400	3/4	26,000	100	
---	---	---	1,200	1-1/2	50,000	20	
12	30	24	30,000	3/16	1,500	Up to 600	Level wind. Variable voltage d-c motor. Removable drum. Variable rate. Fairlead drive. Turntable base.
---	---	---	25,000	0.082	2,675	60	Skid-mounted wireline units. Hydraulic and mechanical drive units provide high horsepower to weight ratio and sensitive operational control.
---	---	---	25,000	0.082	2,675	60	
---	---	---	25,000	0.082	3,500	10	
---	---	---	18,500	0.082	1,150	10	
---	---	---	---	---	---	---	
---	---	---	17,000	3/16	6,000	10	
---	---	---	17,000	3/16	---	---	
6	---	14	450	1/2	1,500 to 2,000	125 to 150	Hoist can be supplied with or without power source. Double roller chain drive. Positive worm screw clutch. External band friction brake.
6	---	14	1,250	3/8	2,000 to 2,600	150 to 200	
---	---	---	---	---	12,000	30	Hydraulic friction clutch, free spooling drum. Electric brake optional.
---	---	---	---	---	24,000	30	
---	---	---	---	---	40,000	30	
---	---	---	---	---	12,000	30	
---	---	---	---	---	40,000	30	
7-1/2 to 13	15 to 30	15 to 20	665 to 1,250	1/2	---	---	Foot-operated brakes. Power take-off and torque converter drive.
10	18	20	400	3/4	---	50	
20	50	25	16,000	3/8	10,000	Up to 400	
30	64	25	12,500	5/8	22,800	Up to 400	

Table XI. Available Winches (Sheet 5)

Manufacturer	Model signation	Type of Power	Power Rating (hp)	Overall Size (inches)			Approx Weight (lb)
				Length	Width	Height	
Stanspec	E2	Elec	3 to 15	39 to 48	21 to 28	16 to 20	375 to 775
	E2-HB	Elec	---	39 to 48	20 to 28	16 to 20	---
	E2-HM	Elec	3 to 25	60 to 108	46 to 104	23 to 51	1,310 to 7,625
	E2-HBM	Elec	---	---	---	---	---
	A2	Air	4 to 8	42 to 48	1C	16-1/4	320 to 375
	E-CD	Elec	25	---	---	---	---
	E-LW	Elec	50	---	---	---	---
Thern	4849 A2	Elec	---	---	---	---	283
	4849 A3	Elec	---	---	---	---	305
	4849 A5	Elec	---	---	---	---	320
	49633 A7-1/2	Elec	---	---	---	---	341
	49633 A10	Elec	---	---	---	---	382
	Weather balloon winch	Elec	---	---	---	---	---
Tulsa	2F23	Power supply	---	---	---	---	922
	3F10	not supplied	---	---	---	---	465
Western Gear	TETHERED BALLOON WINCH SYSTEM						
	Lower power unit	Elec	100	117-1/4	41	45-1/2	5,800
	Upper power unit	Elec	200	117-1/4	41	45-1/2	1,000
	Lower traction unit	N/A	N/A	77-3/4	55	60	---
	Upper traction unit	N/A	N/A	77-3/4	55	60	---
	Lower stowage unit	N/A	N/A	120	75	74-1/2	---
	Upper stowage unit	N/A	N/A	120	75	74-1/2	---
Western Scientific	WSSI 1000	Gas	15	76	43	86	1,200

6. TETHERS - GENERAL DESCRIPTION

Tethers generally have the same requirements of high tensile strength, high strength-to-weight ratio, low drag, low stretch, torque stability, high flexibility, abrasion resistance, and easy splicing. Several balloon tethering configurations have been used. The typical configurations are single, dual, tri, and tandem tethers for multiple balloon flights. The different configurations offer different degrees of freedom which are dictated by the intended balloon operation. Special tethers may be required for a particular balloon usage. Some special tether requirements may involve antenna carrying; power leads in the tether; sensors on the tether; or tubing for transferring helium to the balloon or for air sampling or as a propane line. Tapered or stepped tethers may be desired for high-altitude flights where the weight of a constant-diameter tether cannot be borne. Most tether manufacturers have the capabilities of producing a unique tether to fit a specific need.

7. PROPERTIES AND CHARACTERISTICS OF TETHERS

a. General

In order to select the proper material and construction for a balloon tether, an understanding of the characteristics and the important physical operating properties of a balloon tether is essential. There must be a careful correlation of the factors discussed in the following paragraphs.

Table XI. Available Winches (Sheet 6)

Drum Size (inches)			Cable Storage Capacity		Load Capacity (lb)	Line Speed (ft/min)	Remarks
Drum	Flange	Length	Length (ft)	Dia (in.)			
5.0 to 6.5	11.5 to 14	11 to 18	Up to 400	5/8	1,000 to 10,000	15 to 50	
---	---	---	---	---	1,000 to 40,000	---	
8 to 20	14 to 33	18 to 48	Up to 720	1-1/4	5,000 to 25,000	10 to 25	
---	---	---	---	---	5,000	---	
5	11.5	11.0	1,000	1/4	750 to 4,000	20 to 100	
---	---	---	6,500	---	5,000	120	Safety brake. Torque limiting clutch. Capstan available as an extra.
---	---	---	3,600	3/4	8,000	120	
---	---	---	1,000	1/4	1,800	30	
---	---	---	1,000	1/4	2,600	30	
--	---	---	1,000	1/4	4,400	30	
---	---	---	1,000	1/4	2,800	74	
---	---	---	1,000	1/4	3,600	74	
---	---	---	5,280	1/4	---	300	
7	---	---	2,231	3/8	18,000	---	Manually operated drum brake.
5-7/8	---	---	748	3/8	7,000		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Balloon system was designed for high-altitude tethered balloon systems. System includes level wind, indicators for cable speed, cable tension, cable angle from vertical, and cable azimuth.
N/A	N/A	N/A	N/A	N/A	N/A	N/A	
N/A	N/A	N/A	N/A	N/A	22,800	210	
N/A	N/A	N/A	N/A	N/A	10,000	220	
22-1/2	50	48	12,500	9/16	2,000	0 to 400	
18	38	36	16,000	5/16	1,000	0 to 400	
---	---	---	6,000	1/4	2,000	900	Level wind. Enclosed cab. 360° horizontal rotation.

b. **Strength**

A tether is a flexible member designed to fasten and position a balloon or balloons to the surface of the earth or object thereon. As such, it must possess strength. The measure of a tether's strength is its ultimate tensile breaking strength, and this is equivalent to the external force that must be applied in tension to cause its failure. This breaking strength generally is expressed in pounds or tons. If other forces are involved, such as a shearing from the method of making the attachment or from bending, failure of the tether can actually occur at a tensile stress less than its rated breaking strength. It is important that these factors be recognized by those responsible for designing and operating the tether line equipment, so that a proper safety factor is incorporated. The breaking strengths of typical tether line candidates are given in the tables at the end of this section. The breaking strengths listed are the minimum of each tether and are of the completed rope and not the individual strengths of all the members composing it. The breaking strength of the completed member is lower due to the helical constructions used, and the completed tether strength is less than the sum of individual filament strengths due to the various mechanical interactions.

c. **Weight**

The weight of tether lines is expressed in pounds per foot or in feet per pound. Tether weight varies directly with material, size, and construction. The weight of the tether is a vital design consideration. There is a limit to the length of a tether that can be suspended. The limit is known as its 'breaking length." Refer to subsection 8, "Tether Materials" for a discussion of breaking length.

The ultimate altitudes may be achieved by the use of a tapered tether construction. Tapering is either a continuous construction or a stepping from larger diameter rope to smaller diameter rope. High-altitude tethers that are being considered are made of fiberglass because of its extremely long breaking length, but special handling techniques and special equipment required to handle it are a hindrance to its balloon system application.

d. Flexibility

All operating tethers are subject to bending around sheaves and drums, and the more severe the bending, the more flexible the rope must be. There is a loss of useful strength in the rope when it is bent around a sheave or drum, and the act of bending sets up stresses in the tether that become more serious as the tether becomes less flexible. A tether loses some of its potential strength when it is bent around a sheave as compared with a straight tether. The strength loss is dependent upon the relative sizes of the sheave and the rope, but not upon the number of degrees of bend, provided at least one lay of the tether is in contact with the sheave or drum (in other words, if full bending occurs). The data in Table XII, taken from U.S. Bureau of Standards tests, indicate the relative strength reduction of ropes bent around sheaves as compared with straight rope.

Table XII. Strength Efficiency Under Static Load

Where Sheave Diameter Is	Efficiency of Rope
10 times rope dia	79% of strength of straight rope
12 times rope dia	81% of strength of straight rope
14 times rope dia	86% of strength of straight rope
16 times rope dia	88% of strength of straight rope
18 times rope dia	90% of strength of straight rope
20 times rope dia	91% of strength of straight rope
24 times rope dia	93% of strength of straight rope
30 times rope dia	95% of strength of straight rope

Some of the typical tethers may require larger diameter sheaves due to the nature of use, material, or construction. Refer to the tables at the end of this section as an aid in the selection of sheave and drum. Contact the manufacturer for drum and sheave sizes when special problems are involved. If the bending stress is excessive, and particularly in the case of reverse bending, where the tether is first bent in one direction and then in the other, the tether becomes fatigued. The flexibility of a tether depends primarily on its construction and filament material. As the number of members or strands increases with diminishing filament size, the flexibility increases. Tether flexibility should not be judged completely by flexing the tether by hand. It is the ability of a tether to withstand bending and to resist bending fatigue that is the ultimate measure of flexibility.

e. Abrasion

The ability of a tether line to resist abrasion is almost entirely dependent upon the size of the outer strand. The larger the outer strands, the more abrasion will be required to damage to the point of outer fiber fracture. However, the larger the strands, the less flexible the construction and the tether will be less able to withstand bending stresses. When the outer strands are large, they constitute a large portion of the total tether strength. This becomes a concern when reserve strength of the inner strands is important as a safety factor or when the discarding of a tether is dependent on a visual examination of the outer layer of strands.

Many manufacturers have abrasion-resistant jacketing material with which they encapsulate their tethers. Jackets also provide protection against weather, water, dirt, ice buildup, and ultraviolet rays. However, an added weight must also be considered in the selection of a jacketed tether.

f. Elongation and Elasticity

When dealing with long tethers, particularly when positioning problems are involved, the effects of elongation are a vital consideration. When working below the elastic limit of the tether, there are two types of elongation involved - constructional and elastic.

Constructional stretch is an elongation that becomes noticeable as the tether is put under load. Most of this elongation occurs early in the tether life. The cause of this elongation is the progressive adjustment of the individual strands to a final working position in the tether line. Constructional elongation will usually occur during the first few days of use. It is usually less than one percent of the total length. A great deal of the constructional elongation may be removed by applying a load greater than the estimated maximum operating stress but below the elastic limit of the teth r. If this type of tether (prestretched) is desired, special handling must be used because coiling and uncoiling will return a small amount of the constructional stretch.

Elastic elongation is due to the elastic properties of the tether material below the elastic limit. This type of stretch is recoverable when the load is removed. The elastic elongation of a tether is directly proportional to the load and length of tether under load, and inversely proportional to the material area and the modulus of elasticity of the tether. The formula for the elastic elongation is as follows:

$$\text{Elastic elongation (ft)} = \frac{\text{change in load (lb)} \times \text{length of tether under load (ft)}}{\text{material area (in.}^2) \times \text{modulus}}$$

This formula is approximate. Figures 51, 52, and 53 are elongation curves for Glastran and Samson tethers. Information for other tethers can be found by referring to the tables at the end of this section. If precise determination is required, contact manufacturer of desired tether.

g. Rotation

Rotation of a tether is primarily due to its helical construction, and the direction in which it rotates depends on the lay of the strands. The tendency to roll is noticeable when the tether operates over a sheave or onto a drum. If the tether is not properly placed on the drum, the tether may overwind onto itself, causing extensive bending stress and eventual failure. Rotation may also cause added forces on the balloon which may disrupt stable flight. The usual method of elimination is by means of swivels, which will allow the tether to rotate freely under tension. However, all of the ropes described in tables at the end of this section are built with a non-rotating or no-lay construction. It is very important to specify a non-rotational or torque-balanced tether in a balloon system.

h. Safety Factor

The factor of safety of a tether line is the ratio of the strength of the tether to its maximum design load. In other words, it is the number of times the tether is stronger than the load. For example, if a tether line has a breaking strength of 10,000 pounds, it would have a safety factor of 2 if the design load were 5,000 pounds or a safety factor of 4 if the design load were 2,500 pounds.

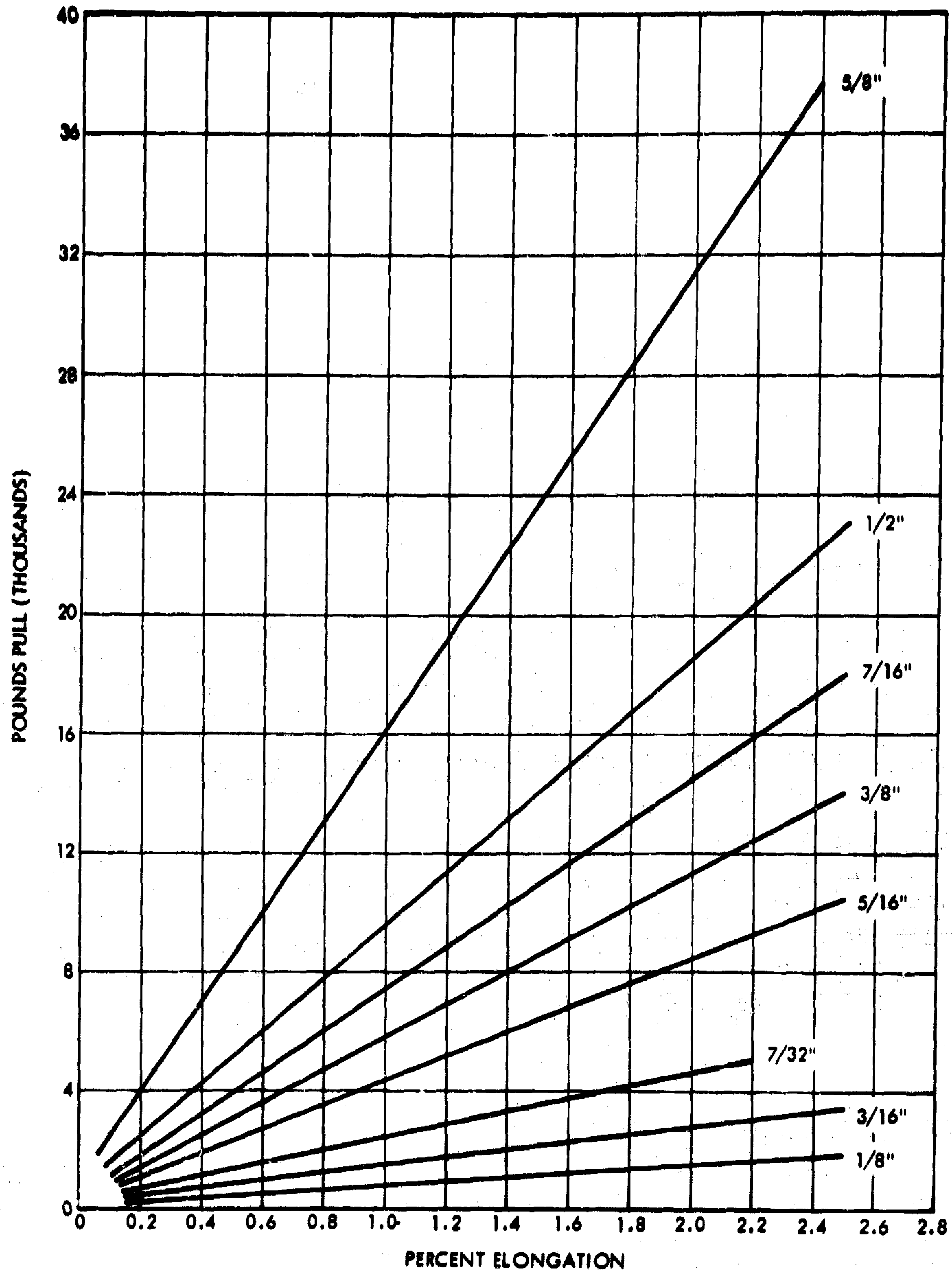


Figure 51. Glastran Elongation No. 1 for Various Diameters

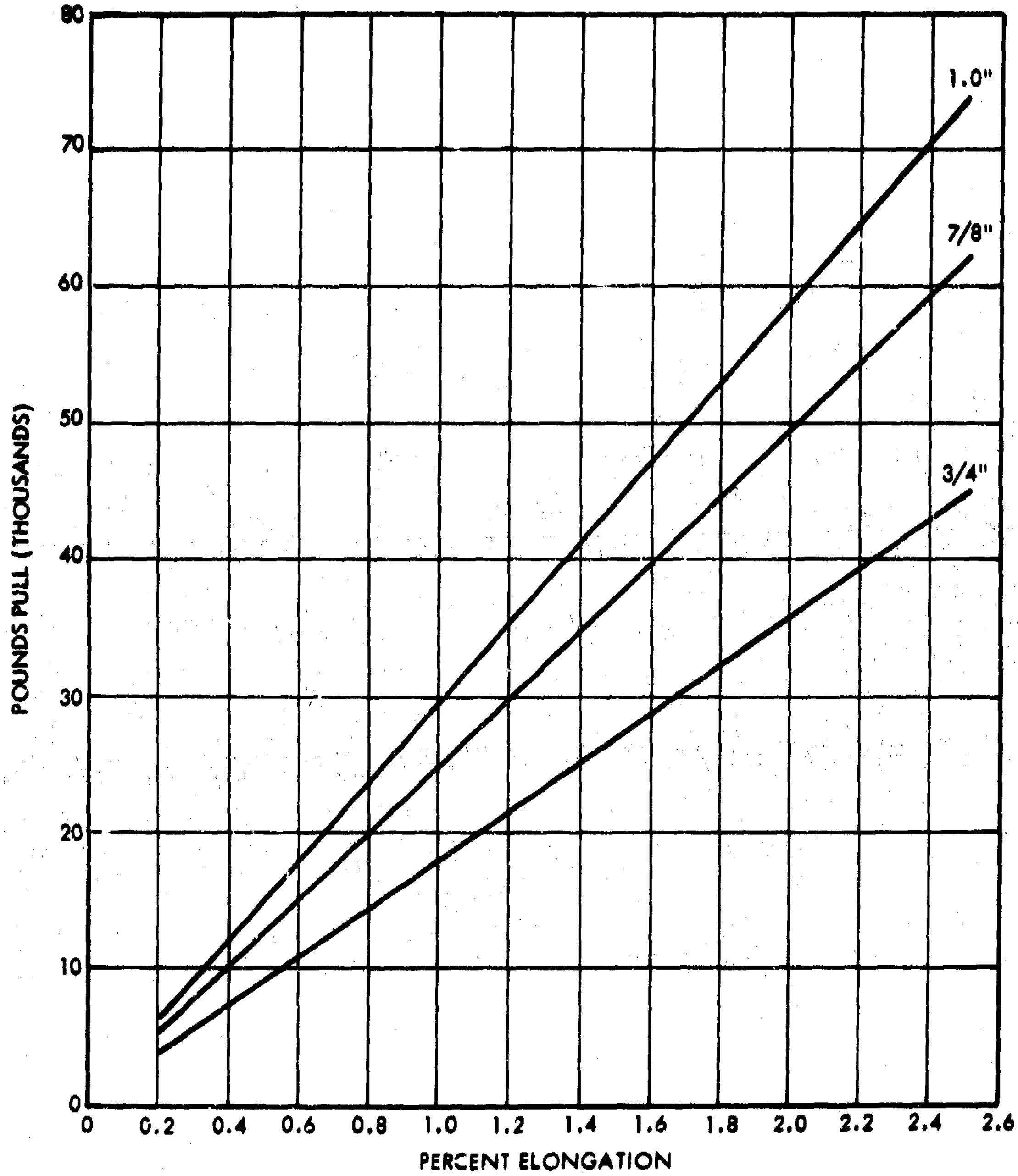


Figure 52. Glastran Elongation No. 2 for Various Diameters

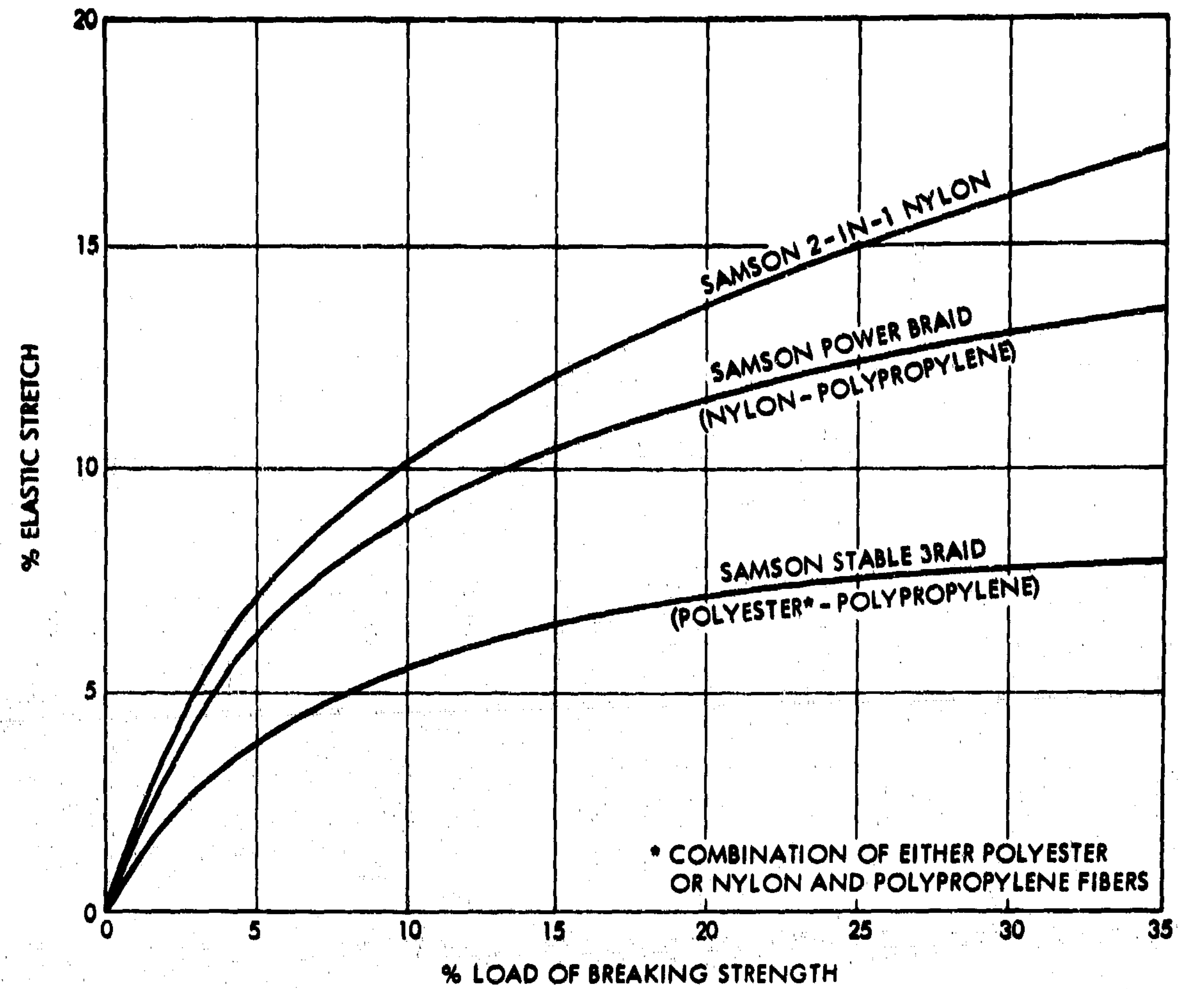


Figure 53. Elastic Elongation of Samson 2-in-1 Braided Rope

The proper safety factor is of great importance, not only for safety but for economy. It is difficult to establish arbitrary values for the safety factor, but a higher factor usually means greater operating economy. When risk is involved, the safety factor should be considerably higher than where no injury to personnel can occur. Factors of safety of about 2 are average for a balloon application; however, special cases may require this number to be higher.

Balloon tethers frequently involve higher average ratios of working load to ultimate strength than those recommended by manufacturers. A reduction in working life results.

8. TETHER MATERIALS

There are various materials with which tethers can be made. Table XIII shows a comparison of various tether lines in terms of "breaking length." Breaking length is a method of expressing the strength-to-weight ratio. Breaking length is the vertical height to which a cable can theoretically be raised before it breaks of its own weight. The theoretical breaking length can be calculated by dividing the breaking strength in pounds by the weight in pounds per foot. Theoretically, the breaking length of cables made from one particular material should be the same for all sizes of tethers. In actual practice, the breaking length decreases as the

Table XIII. Comparison of Tether Materials

Cable Material	Construction	Weight (lb/ft)	Strength (pounds)	Diameter (inches)	Breaking Length (feet)
S-Glass Monostrand	Single strand	0.0094	3000	0.125	319,000
E-Glass Glastran	1 x 7	0.0095	1800	0.128	190,000
Samson 2-in-1 Nylon	Braided	0.0166	2100	0.250	126,500
Carbon Rocket Wire	1 x 19	0.0310	3275	0.117	105,500
Music Wire	1 x 19	0.0360	3250	0.121	90,500
NS-355 Stainless Steel	7 x 19	0.0296	2370	0.138	80,000
Dacron Nolaro	No-lay	0.0210	1650	0.250	78,500
Type 304 Stainless Steel	3 x 7	0.0402	2800	0.1562	69,500
NS-302 Stainless Steel	7 x 19	0.0290	1960	0.136	67,500
Mylar Rope	Three-strand	0.0213	1400	0.125	65,800

diameters increase. From this we can see that breaking length is a good comparison for basic material strength. However, it should not be used as the only guide to tether selection. Figures 54, 55, and 56 show comparisons of breaking strength versus diameter, breaking strength versus weight, and breaking strength versus cost for various tether candidates. All these and more must be considered for the final selection of a balloon tether. The tables at the end of this section contain pertinent data and descriptions of typical tethers that may be purchased from manufacturers. The designer can enter the information on a balloon tether strand and cable data sheet (Figure 57). The data sheet can then be sent to the tether manufacturer for review and final approval to make sure that his particular tether can suit the particular requirement.

9. TETHER LENGTH

The length of a tether is determined by the design altitude and the design winds to be encountered. In other words, with no wind, the balloon will carry the tether vertically from its mooring. If the tether is let out, the balloon will rise until the weight of the tether balances the static lift of the balloon or until the tether reaches its breaking length and fails from its own weight. The point at which the balloon buoyancy equals the weight of the tether is the balloon's static ceiling. However, as soon as the wind blows, the balloon and cable drag will cause the balloon to drift downwind and the cable will become inclined to the vertical. The aerodynamic force on the tether can be assumed to act normal to the length of each tether element. The inclination of the tether to the vertical causes a component of the wind force to act vertically downward on the tether. The summation of these forces causes the balloon to sink to a lower altitude. The lowering of the balloon height will require more tether to be payed out in order to attain the original static ceiling. Since the balloon lifts more cable clear of the ground, the vertical force on the mooring decreases and the angle of the tether at the mooring also decreases. The tether at the mooring will eventually reach the horizontal, and no vertical force will exist there. At this point, the balloon has reached its ceiling for that wind speed. Any more tether payed out would lie on the ground. In order to select the proper amount of tether line, it is necessary to calculate the configuration (single-, dual-, or tri-tether) that

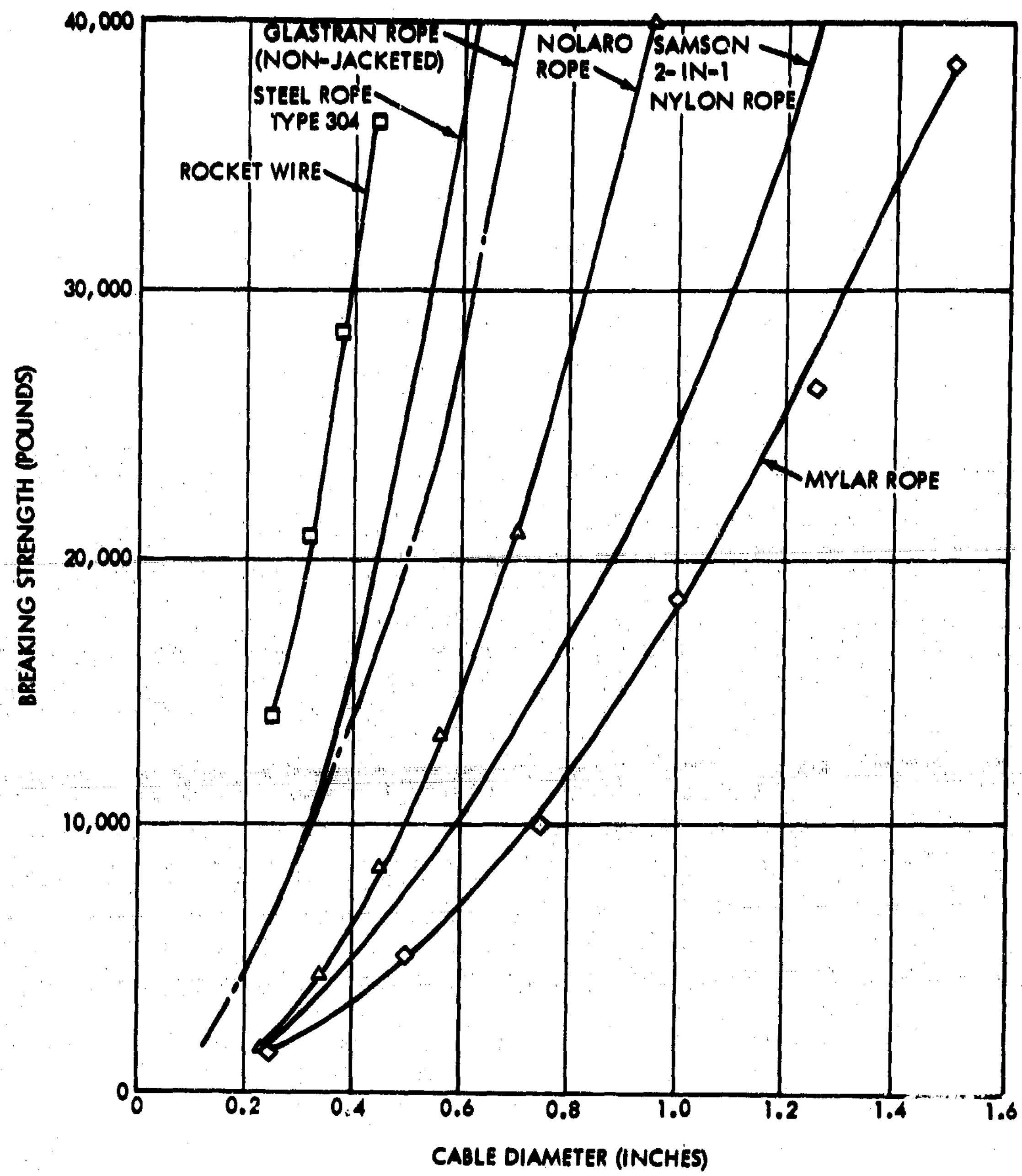


Figure 54. Strength-to-Diameter Ratios for Various Candidate Balloon Tether Materials

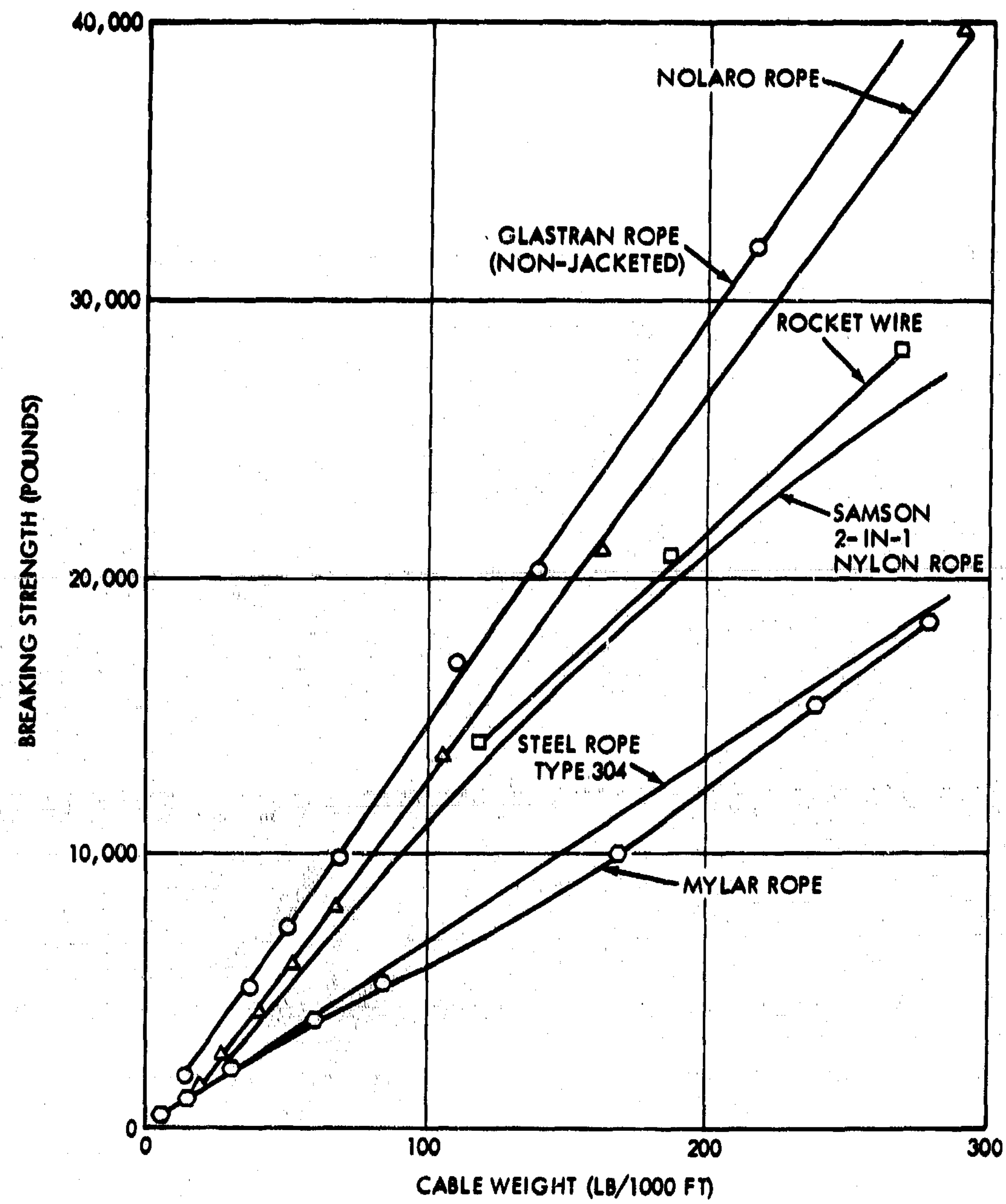


Figure 55. Strength-to-Weight Ratios for Various Candidate Balloon Tether Materials

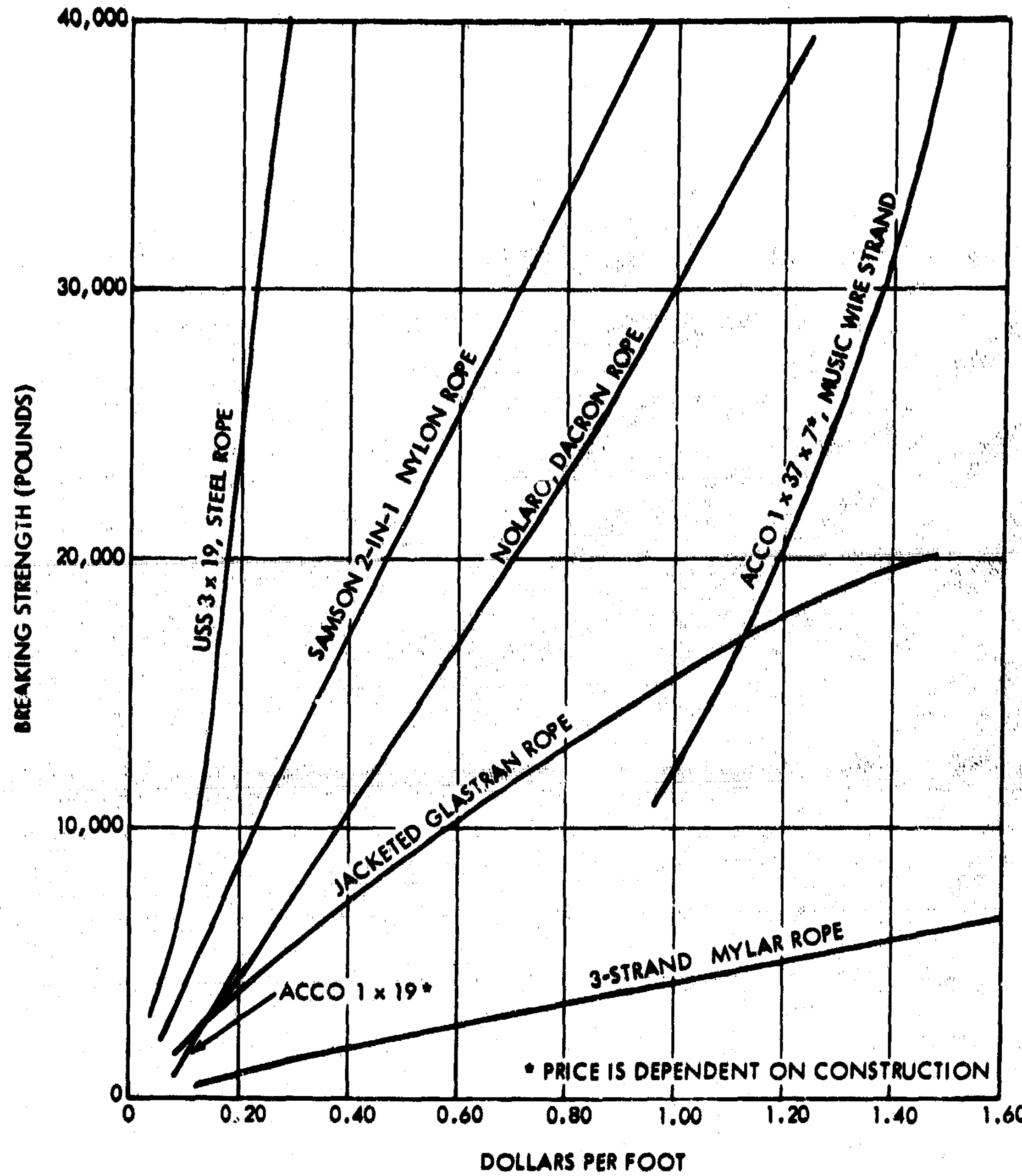


Figure 36. Strength-to-Cost Ratios for Various Candidate Balloon Tethers

Firm ____________________ Order No. ________
Address ____________________ Request No. ________

City ____________________ State ______

Attention ____________________ Dept. ______

CABLE APPLICATION ____________________

Construction Preferred, Step ☐ Constant Dia. ☐ Antenna ☐

MECHANICAL PROPERTIES OF CABLE

Length, Continuous ____________________ Number of Length Req. ________
Max. Work Load ________ Max. Shock Load ________ Safety factor ________
Weight in air ________ Material of Tensile Members ________
Construction and Size ________ ________
Life Expectancy; Wk., Mo., Yr ________ Use Cycle ________ Storage Conditions ________
Environment ________ Temp. ________ Min. ________ Max. ________
Ambient, Sea ______ Air ______ Earth ______ Space ______ Pressure range ______
Outer Jacket, Material ________ Thickness ________ Max.Cable O.D. ________
Attachments ____________________

CONDUCTOR PROPERTIES OF CABLE
INDIVIDUAL CONDUCTORS*

Capacity ________ Type ________, Size ________ AWG ________
Volts ________ AC, DC AMPS ________
Dielectric Material ________ Temp. Rating ________
Impedance-Capacitance ____________________
Construction ________ Stranding ________
Shielding, % Coverage ____________________
Attenuation Required ____________________
Color Code ____________________
Bedding or jacket for conductor cable ____________________
Conductor location, surface ☐ or center of cable ☐
Frequencies Used ________ Conductor skin depth ______ in.

*SPECIFY SEPARATELY INFORMATION ABOVE FOR EACH SIZE AND TYPE CONDUCTOR REQUIRED. USE ADDITIONAL SHEETS.

SPECIFICATIONS OF WINCH

Winch Type: Drum ☐ ; Capstan, single ☐ ; Capstan, double ☐
Drum; grooved for ______ in. cable, or smooth drum ____________
Number of layers of cable on drum ______ at ______ lb. cable tension.
Minimum drum diameter ______ in.; Minimum sheave diameter ______ in.
Reeling speed, constant ________ ft. per min.
variable from ________ f.p.m. to ________ f.p.m.
Acceleration characteristics ____________________

Figure 57. Balloon Tether Strand and Cable Data Sheet

the tether cable assumes when the selected design wind blows. Various methods for calculating the approximate single-tether configuration exist. The "Hollingdale and Wild" method for calculating tether configuration is applicable to only low-altitude, constant-diameter tether and constant wind profile balloon flights (Reference 7). If a more sophisticated and exact method is desired, refer to the "cable" listings in the Bibliography. Many of the reports listed provide tables, formulas, and computer programs with which to solve the more complex tethering problems.

10. TETHER DIAMETER

The tether diameter should be as small as possible and still retain the strength capabilities necessary to maintain the balloon's position in all anticipated winds. A tether's drag, strength, and weight vary as functions of the tether diameter. The diameter of the tether will determine sheave size, size of drum, and amount of cable stored on the drum. Refer to the earlier parts of this section for determination of proper drum and reel capacity.

11. TETHER CONSTRUCTION

Tether construction is the general term that includes number of strands; size, number, and arrangement of the members in the strands; the lay; the core; and the type of fabrication. Innumerable constructions are possible by varying the above factors, and the problems involved have been the subject of continuous study, research, and test.

A strand is a group of members of metal, synthetic, or natural material, and the number of strands denotes how many of these groups are laid around the core to form the tether. The number of strands in a tether may vary depending on the application. Figure 58 shows typical cross sections of wire rope constructions. Most constructions are shown, but only a few of these may have been used for balloon tethers. There are various other constructions that are used dependent on the material. Typical ropes, cables, and tension members that may be used as tether lines are listed in the tables at the end of this section. The "Design Construction" column in these tables indicates the type of construction used for that particular tether line. Most of these constructions are of the torque-balanced type.

"Lay" is the term used to describe the twist or pitch of the members and strand used in the tether. It is very important in giving the tether elasticity, stability, resistance to crushing, increased flexibility, and the ability to absorb shock loads. The length of the lay is the distance along the tether that is required for one strand to travel all the way around the core. There are various types of rope lay constructions. The construction that should be noted here is the non-rotating. This type of construction is used in free suspension, where rotation must be restricted. The tether is constructed in two layers. The inside layers are laid in one direction, and the outside layers are laid in the opposite direction. Therefore, the tendency for twisting is balanced.

Another method of manufacturing a non-rotating type of tether is to use a no-lay construction. No-lay construction is made by paralleling low twisted members under as nearly equal tension as possible and holding the bundle together by extruding a covering jacket. The no-lay construction eliminates the loss of strength and increase in elongation, which results when fibers are put in the helical position by twist, lay, etc of conventional stranded tethers. Another type of construction is used by the fiberglass cable manufacturers. The construction of the cable is accomplished by collimating glass fibers, coating with a resin sizing, and curing the resin to form an integral strand. The strands may be used individually or put into the conventional wire rope construction form. Other constructions used are the braided constructions. This is a more flexible construction and is usually used with the more flexible natural and synthetic fibers. Most manufacturers can provide tethers with integral electrical conductors. Table XIV shows three conductors that could be used in tether constructions. (These conductors are manufactured by Columbian Rope Co., Auburn, New York.) If conductors are used, additional weight must be added to the tethers. Consult Table XIV for specifications. Most manufacturers are also equipped to produce either a stepped or tapered cable upon request.

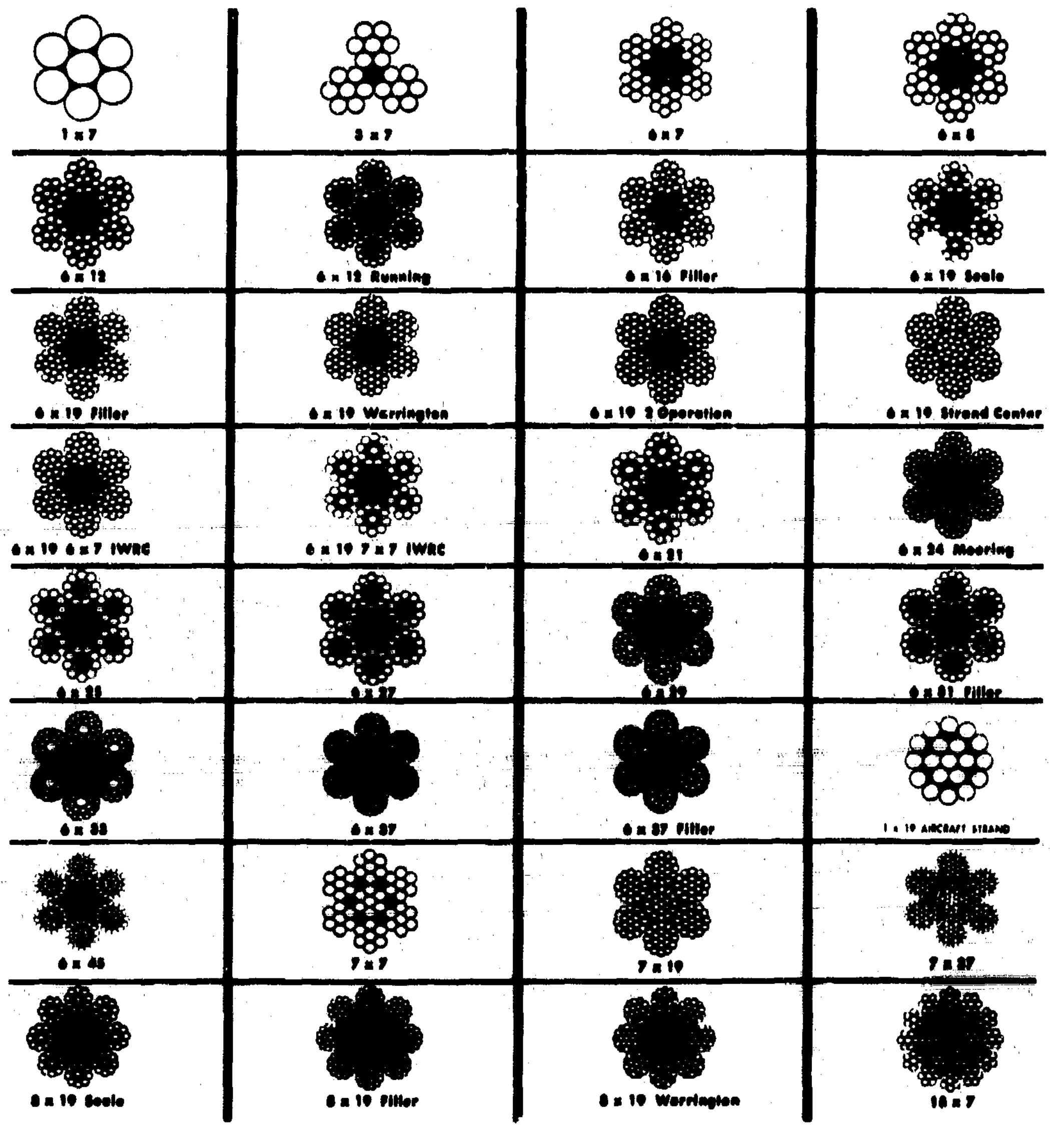


Figure 58. Typical Cross Sections of Wire Rope Construction

Table XIV. Elastic Conductor Specifications

Property	No. 3	No. 24	No. 17
Approximate equivalent AWG	No. 22	No. 24	No. 17
OD Size (inches)	0.098	0.129	0.158
Length per pound (feet) . . .	164	117	55.5
Weight per 1000 feet (pounds)	6.1	8.5	18.0
Core	Nylon	Nylon	Nylon
Number of copper wires . . .	18 - No. 34 AWG	18 - No. 34 AWG	16 - No. 28 AWG
Insulation material	PVC with nylon overlay	HM-LD-PE*	HM-LD-PE*
Approx strength at break (pounds)	90	275	550
Approx elongation at break (percent)	10	16	17
Max resistance (ohms per 1000 feet)	16	25	5.0
Colors available	Red, white, dark blue	Red, white, black	Red, white, black
Specific use	Wire rope core	Other	---

*ASTMD1248-60 Type 1, Grade 4, Class B

12. FITTINGS

a. General

Various types of end fittings and connections can be used to attach the balloon to the tether line and the tether line to the ground. The type of end fittings to be used will depend on the purpose and type of tether to be used. The following paragraphs suggest various types of fittings available to the system designer. However, the designer of the system should contact the tether manufacturers for data and suggestions as to the proper choice.

b. Knots and Splices

The most common end connection that can be used on small balloon systems and handling lines is the knot. The knot has the limitation of being usable only on small, highly flexible ropes, but has the advantage of being quickly done in the field. Table XV gives a comparison of the strength of knots tied with Samson's 2-in-1 braided rope. If another brand or type of tether line is used, contact the tether line manufacturer for knot efficiency.

Another type of connection is the splice. The splice may stand alone or may be used in conjunction with a thimble or hook. Figure 59 shows typical thimbles that can be used with the eye splice in order to make a good end fitting.

Table XV. Knot Strength Comparison

Type of Knot	Percent of Strength Retained	
	2-in-1 Braid	3-Strand
Buried eye splice	92	94
End-for-end	90	90
Timberhitch	67	60
Two half hitches	70	62
Bowline	69	65
Square knot	68	68
Overhand knot	68	71
Fisherman's bend	69	68
Carrick bend	70	62

NOTE: Knots tied with Samson's 2-in-1 braided rope.

c. Swaged Fittings

Swaged fittings or terminals are usually used on wire rope tethers. There are several types of swaged fittings from which to choose. The proper choice will depend on the function of the system. Swaged fittings will develop 100 percent of the rated breaking strength of the wire rope. Figure 60 shows several typical swaged end fittings.

d. Potted End fittings

Potted end fittings can be used with almost all of the tethers. Special potting procedures should be followed when applying this type of end connection to certain types of tether lines. The tether manufacturer should be consulted for the proper procedure of potting his particular tether. In general, the method consists of the following procedure:

(1) Place the tether in a socket prescribed for that tether.

(2) Splay the end of the line in the manner prescribed by the manufacturer.

(3) Pull the splayed end into the socket.

(4) Fill the socket with molten zinc or resin compatible with the tether material.

(5) Allow to harden.

Figure 61 shows a modified end fitting and a splaying method used on the monofilament type Aerostrand. Figure 62 shows a representation of the potting method used on Glastran cable. It is recommended that all potted end fittings be x-rayed before use to ensure full penetration of the zinc or resin. Figure 63 shows four potted end fittings. End fitting A received full penetration of resin. End fittings B, C, and D did not, as can be seen by the apparent voids. If a socket is properly potted, it will develop 100 percent efficiency of the rope. Figure 64 shows two different styles of potted end fitting sockets. Other styles are also available.

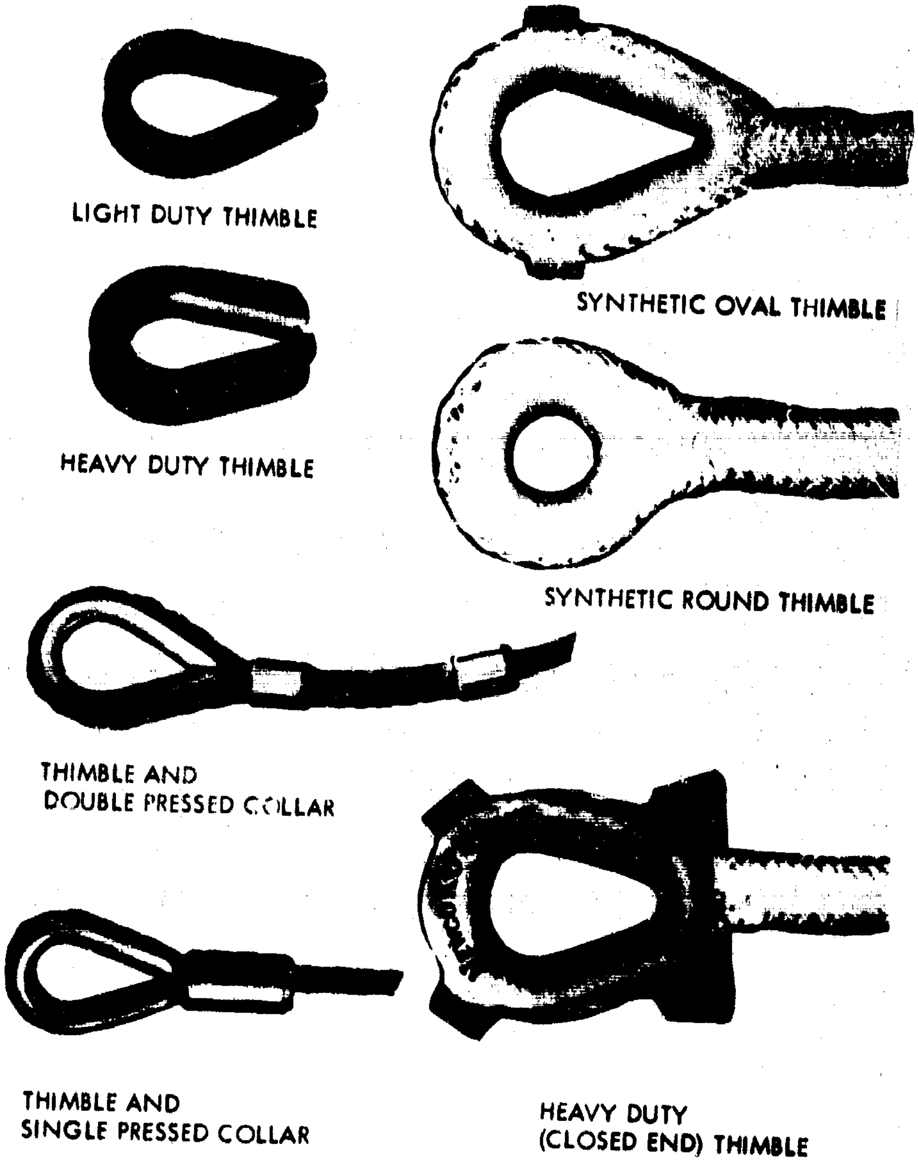


Figure 59. Thimble End Fittings

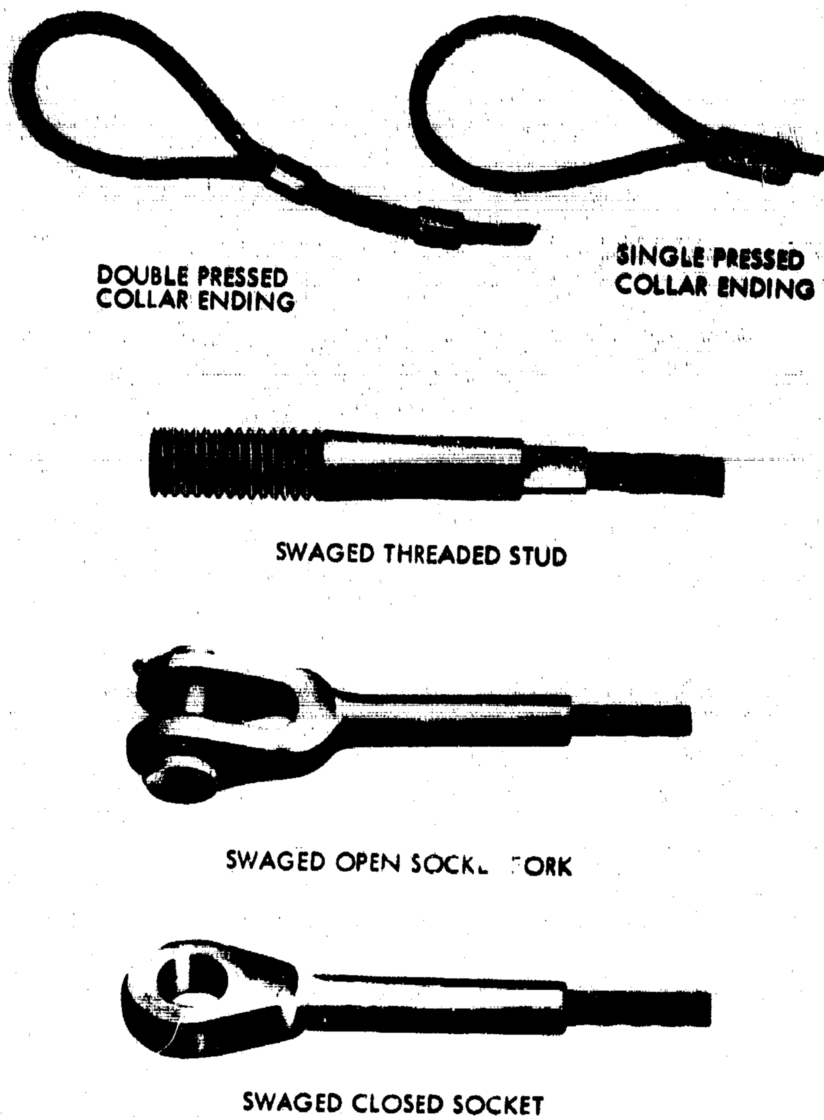


Figure 60. Swaged End Fittings

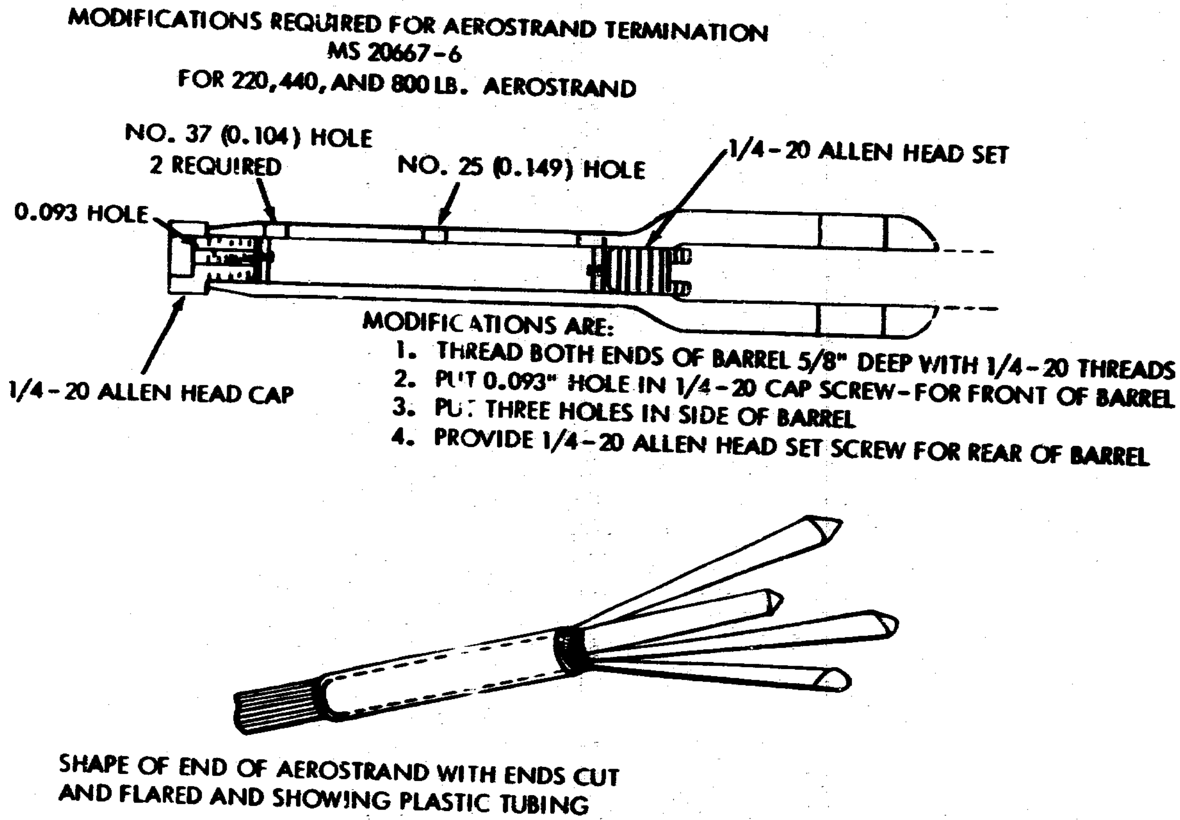


Figure 61. Aerostrand-Monostrand Termination Requirements

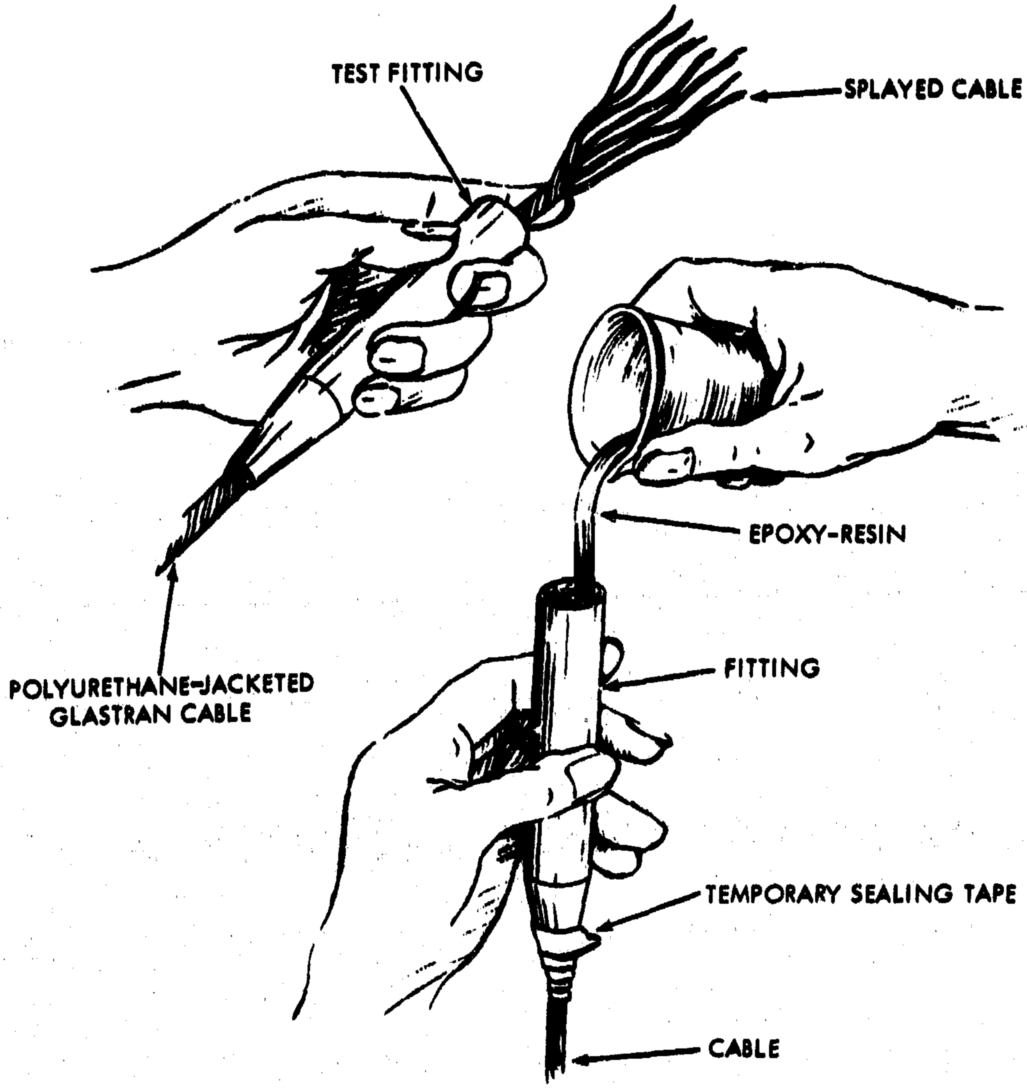


Figure 62. Typical Potting Technique Used on Fiberglass Tethers

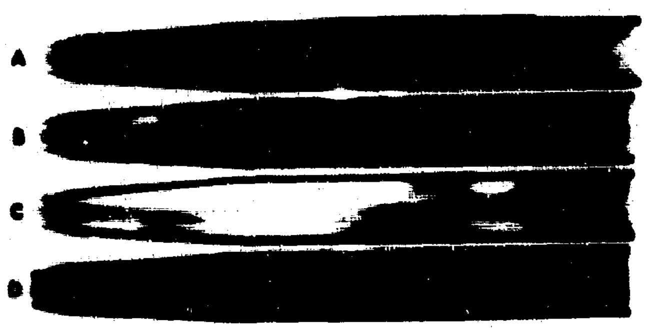


Figure 63. Typical Potted End Fitting X Ray

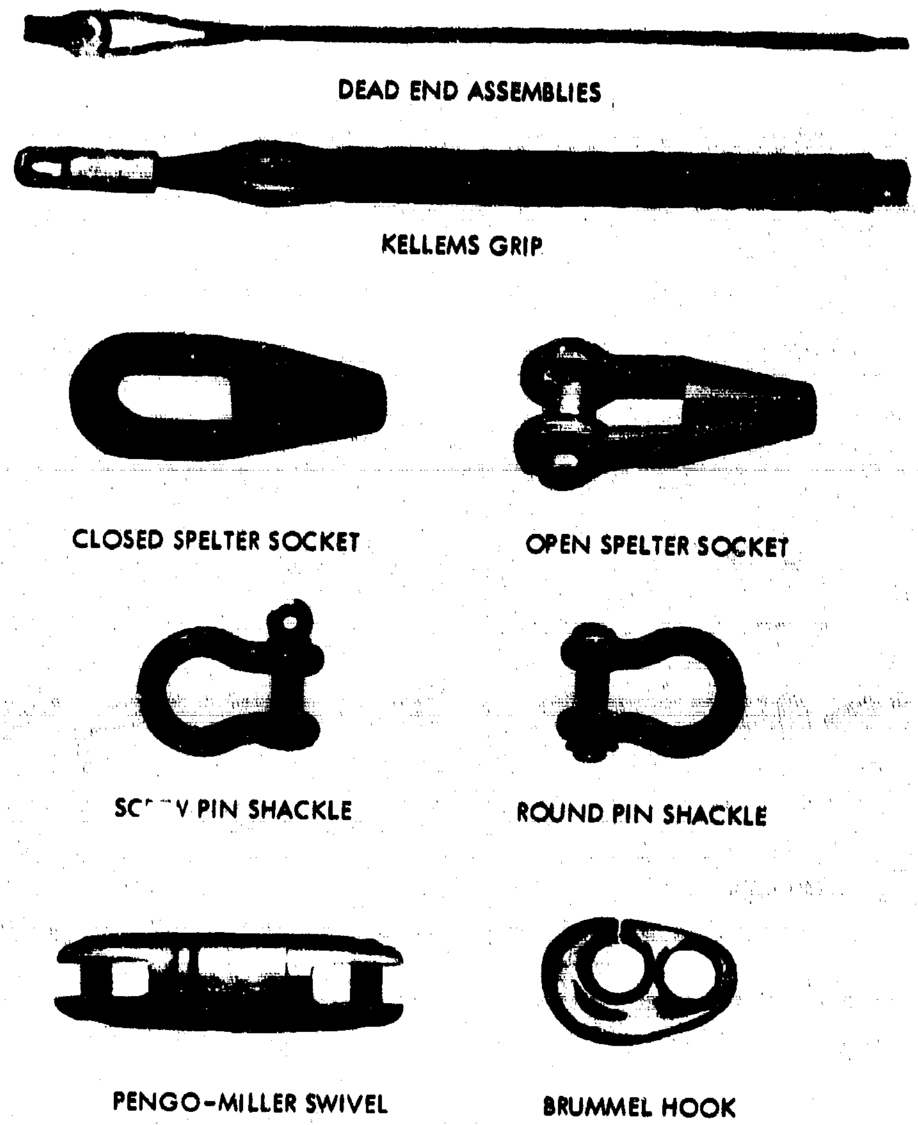


Figure 64. Miscellaneous End Fittings

e. Grip-Type Fittings

The grip or friction type of fitting may be used with almost all of the tether lines, with the exception of the very small, smooth-strand type of tether. Figure 64 shows two types of the friction grips. The first type shown is the wrap-around type. The idea of the grip is to wrap the preformed metal fitting around the tether line so a friction bond is set up, thus restricting the tether line from being pulled out. The grip type of end fittings are capable of developing 100 percent of the tether line's rated breaking strength.

The second type is the "Chinese finger grip" type. The formal name is "Kellems grip." Kellems grip is a mechanical wire-mesh holding device. The tether is placed in the grip, and as the load on the tether increases, the grip tightens. Kellems grips can be used for modest loadings. Breaking strength can be supplied by the manufacturer.

f. Miscellaneous Fittings

There are several other mechanical devices that should be mentioned here. Shackles are used to connect different pieces of equipment to the tether line arrangement. Figure 64 shows two types of shackles that can be connected rapidly in the field. If an extremely fast connection of tether line to balloon is required, the Brummel hook shown in Figure 64 is a quick method. Figure 65 shows the manner in which the two identical Brummel hooks are connected. Swivels are quite often used in the tether line to dissipate any rotation that might be generated by either the balloon or the tether. Figure 64 shows a typical Pengo-Miller swivel.

A shear link of some form is frequently incorporated in a balloon-tether system. The shear link is a safety measure to avoid the loss of the balloon by failure of the tether line. The shear link is a device that has a breaking strength less than the tether line. The shear link may take the form of another lighter piece of tether line, spliced into the line at the suspension point, or a mechanical device such as shown in Figure 66, with a rivet or bolt with a shear value less than the breaking strength of the tether line. When the tension in the balloon tether approaches the breaking strength of the tether line, the shear link will break and the balloon will rise. A rip cord attached to a rip panel in the balloon and the shear link attachment will rip the balloon. The use of this system avoids complete loss of the balloon and payload. Figure 66 shows a typical mechanical shear link in the system. A chain added to the

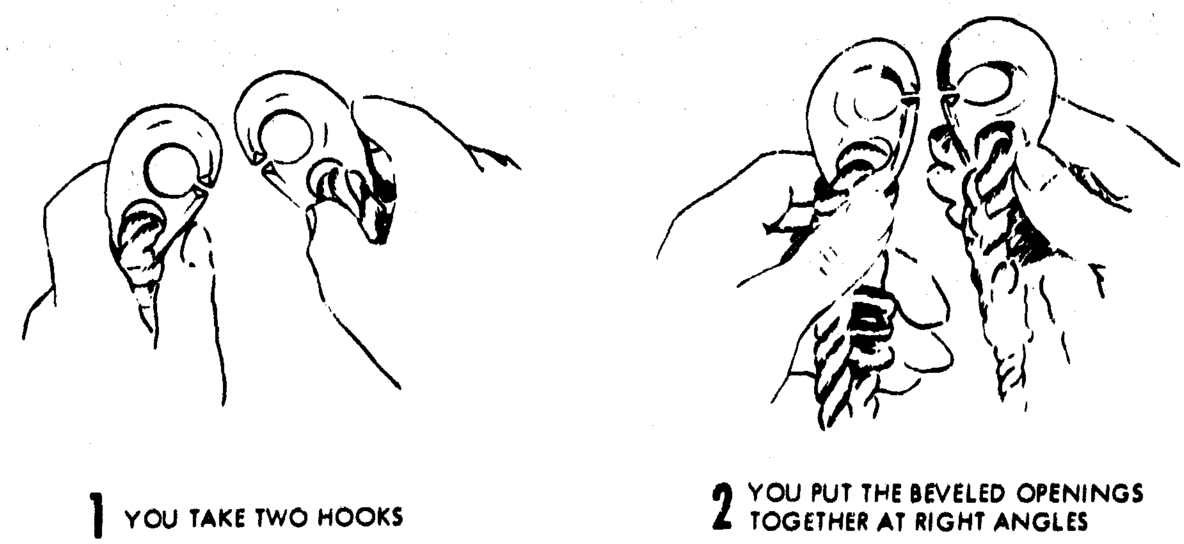


Figure 65. Brummel Hook Connection

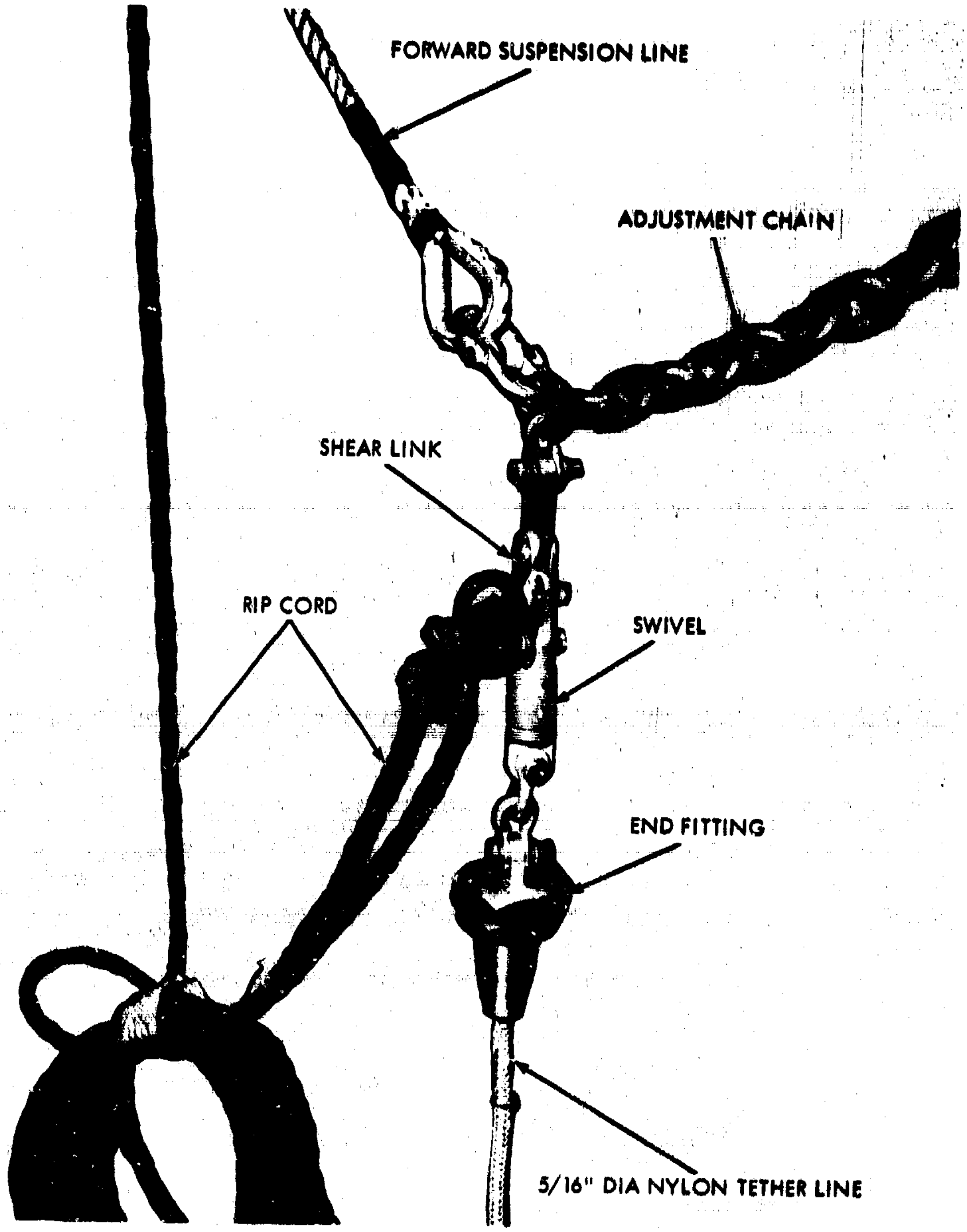


Figure 66. Typical Bridle or Suspension Point

suspension system of the balloon provides a simple method of adjusting angle of attack without adjusting all the suspension lines. Figure 66 also shows a typical suspension point arrangement. The addition, extraction, and order of the fittings and devices may vary according to the weight limitation, purpose, and type of balloon involved in the system.

13. AVAILABLE TETHERS

Tables XVI through XXII represent a collection of tether lines that have been or could be used in a tethered balloon system. The tether lines listed in the tables are representative of the many different types of material and constructions that can be manufactured. The data, approximate prices, and general information are valid as of 1968 and should be used for engineering approximations only. The names and addresses of manufacturers who produce tethers or have the capability are listed below. Other companies not listed here may also produce similar tethers and should also be contacted for literature and suggestions if necessary.

American Chain & Cable Company, Inc.
Automotive and Aircraft Division
1022 E. Michigan St.
Adrian, Michigan 49221

Anchor Specialty Mfg.
300 Hollister Road
Teterboro, New Jersey 07608

Armco Steel Corporation
703 Curtis Street
Middletown, Ohio 45042

Bergen Wire Rope Company
1234 Gregg Street
Lodi, New Jersey 07644

Boston Insulated Wire
65 Bay Street
Boston, Massachusetts 02125

Braincon Corporation
13 Shenandoah
Marion, Massachusetts 02738

C.F. & I. Steel Corp.
Box 1920
Denver, Colorado 80201

Columbian Rope Company
Auburn, New York 13021

Gulton Industries
212 Durham Avenue
Mituchen, New Jersey 08840

Lindgren Assoc. Inc.
P.O. Box 61
Wilton, Connecticut 06897

Marsh & Marine, Div Vector Cable
5123 Gulfton Drive
Houston, Texas 77036

Samuel Moore & Co.
Mantua, Ohio 44255

Morse Controls, Inc.
Hudson, Ohio 44236

North American Aviation Ocean Systems Operations
3370 Miraloma Ave.
Anaheim, California 92803

D.G. O'Brien, Inc.
500 Cochituate Road
Framingham, Massachusetts

Oceanographic Engineering Corp
Hydro Products Division
P.O. Box 2528
San Diego, California 92112

Ocean Research Instruments
501 Northwest 65th Street
Seattle, Washington 98107

Owens-Corning Fiberglas Corp
Office of Aerospace and Defense
717 Fifth Ave.
New York 22, New York

Packard Electric
Division of General Motors
P.O. Box 431
Warren, Ohio 44482

Pennsalt Chemicals Corp.
3 Penn Center
Philadelphia, Pennsylvania 19102

Pennsylvania Wire Rope Corp.
905 First Street
Williamsport, Pennsylvania 17701

Precision Surveys Inc.
Point and Erie Street
Camden, New Jersey 08102

Rochester Ropes, Inc.
P.O. Box 312
Culpeper, Virginia 22701

Samson Cordage Works
470 Atlantic Ave.
Boston, Massachusetts 02210

Sea Equipment, Inc.
92 South Front Street
Bergenfield, New Jersey 07621

Simplex Wire and Cable Co.
Box 479
Portsmouth, New Hampshire 03801

Teleflex, Inc., Aerospace Div.
Church Road
North Wales, Pennsylvania 19454

United States Plastic Rope, Inc.
711 Hamilton Ave.
Menlo Park, California 94025

United States Steel Corporation
Wire Rope Products
71 Broadway
New York, New York 10006

Table XVI. American Chain and Cable Company Tethers

Part No.	Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) See Note 4
SMOOTH STRAND, TYPE 1 MUSIC WIRE (See Note 1)						
RA-6643	0.038/0.040	1 x 7	3.85	380	See Notes 2 and 3	2.50
RA-6281	0.042/0.044	1 x 7	4.52	440		2.50
FA-6836	0.048/0.050	1 x 7	5.76	560		2.60
RA-6639	0.053/0.055	1 x 7	7.01	680		2.70
RA-6330	0.062/0.064	1 x 7	9.39	880		3.00
RA-6940	0.070/0.072	1 x 7	11.68	1,120		3.00
RA-6844	0.080/0.082	1 x 7	15.42	1,390		3.20
RA-7369	0.095/0.097	1 x 19	21.50	2,010		7.00
RA-7371	0.104/0.106	1 x 19	25.90	2,390		7.40
RA-7373	0.114/0.117	1 x 19	31.00	2,800		7.90
RA-7375	0.121/0.124	1 x 19	36.30	3,250		8.50
RA-7377	0.133/0.136	1 x 19	42.00	3,710		9.00
STRANDED-COMPACTED MUSIC WIRE (See Note 5)						
N/A	0.041	1 x 7	5.50	290	See Notes 2 and 3	7.00
N/A	0.046	1 x 3	5.00	302		7.10
N/A	0.050	1 x 3	7.00	370		7.20
N/A	0.055	1 x 3	8.00	420		7.50
N/A	0.063	1 x 3	10.00	530		7.80
N/A	0.068	1 x 3	11.80	613		8.20
N/A	0.078	1 x 3	14.00	800		8.60
N/A	0.137	1 x 19	47.00	3,530		15.00
N/A	0.213	1 x 19	105.00	5,000		20.00
N/A	0.235	1 x 19 x 7	128.90	7,900		100.00
N/A	0.245	1 x 19 x 7	141.00	8,900		100.00
N/A	0.269	1 x 37 x 7	123.00	11,600		125.00
RA-8937	0.117	3 x 7	31.6	2,350		11.00
RA-8939	0.127	3 x 7	37.3	2,550		11.50
RA-8941	0.137	3 x 7	43.6	3,250		12.00
RA-8943	0.117	1 x 13	35.0	3,000		15.50
RA-8945	0.127	1 x 13	39.0	3,350		16.00

Table XVI. American Chain and Cable Company Tethers (Continued)

Part No.	Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) See Note 4
STRANDED-COMPACTED MUSIC WIRE (See Note 5) (Continued)						
RA-8947	0.137	1 x 13	47.0	4,000	See Notes 2 and 3	16.50
RA-8303	0.143	1 x 19	45.00	4,000 (See Note 6)		10.00
N/A	0.250	1 x 37 x 7	118.00	11,050		95.00
N/A	0.375	1 x 37 x 7	267.00	23,750		125.00
N/A	0.500	1 x 37 x 7	476.00	40,500		150.00
ARMORED, MIL-C-5765D (See Note 7)						
RA-6280	0.094/0.098	ACCO Armored	22.00	1,230	See Notes 2 and 3	6.00
RA-1784	0.125/0.130		40.80	2,160		6.00
RA-4906	0.177/0.182		75.70	4,000		7.00
RA-4986	0.198/0.203		94.12	5,100		10.00
RA-7507	0.128		43.50	1,535		17.00
RA-8368	0.160		65.80	2,550		18.00
RA-7459	0.210		110.00	4,840		20.00

NOTES:

1. Similar sizes of Rocket Wire grade strand are available with approximately 17% more strength and some loss in ductility.
2. ACCO tether lines are available in any length desired. Extremely long lengths may require an increase in price.
3. ACCO has developed a splicing technique that will operate over sheaves and drums and provide a strength equal to the smaller tether member.
4. Prices listed were provided at time of publication; prices are OEM and for engineering estimates only.
5. Available in IPS, VHS, Rocket Grades, carbon, stainless, or coated wires.
6. Plastic jacketed.
7. Flat wire armor can provide greater abrasion resistance, minimizes torsion induced by tensile loadings and constructional stretch.
8. A minimum of 30 times the tether diameter should be used as a guide for sheave and drum selection.
9. ACCO can also produce conductors or tubing in their tethers upon request.
10. Approximate maximum length at yield (in 1000's of ft) = $\frac{0.7 \text{ (breaking strength)}}{\text{weight per 1000 ft}}$

Table XVII. Columbian Rope Company Tethers

Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds) See Note 2	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) See Note 5
NOLARO, POLYVINYL CHLORIDE (PVC) JACKETED (See Notes 1 and 4)					
0.250	See Note 3	23.0	1,650	See Note 4	8.00
0.312		35.2	2,750		13.50
0.375		53.6	4,400		18.80
0.437		72.8	6,050		25.50
0.500		94.5	8,250		33.00
0.625		144.0	13,750		50.00
0.750		208.0	21,000		73.00
1.000		361.0	40,000		126.00
NOLARO, POLYETHELENE (PE) JACKETED (See notes 1 and 4)					
0.25	See Note 3	20.1	1,650	See Note 4	7.00
0.312		30.9	2,750		10.07
0.375		46.4	4,400		16.00
0.437		62.6	6,050		21.90
0.500		82.7	8,250		29.00
0.625		127.9	13,750		44.50
0.750		187.6	21,000		66.00
1.000		333.0	40,000		116.00

NOTES:

1. Typical examples of Dacron Nolaro with PVC and PE jackets are given.
2. Approximate breaking strengths are given.
3. Jacketed, parallel low twist yarns.
4. Nolaro is custom made to order in quantities of 100 pounds or more of a size. This weight will determine the minimum length of a tether that can be ordered.
5. Nolaro prices were calculated on the following basis:
   A charge of $150.00 is made for setup plus
   $3.50/lb for Dacron Nolaro
   3.00/lb for Nylon Nolaro
   2.50/lb for Polypropylene Nolaro
6. Dacron Nolaro elongation (approx) can be calculated by using the following data:

Load as % of Breaking Strength	Approx % Elongation
10	1.0
20	1.8
30	2.8
50	4.3
70	5.6

7. Conductors can be incorporated in the tether upon request.

Table XVIII. Owens-Corning Fiberglas Corporation Tethers (Aerostrand)

Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars)
0.029/0.033	See Note 1	0.55 (±0.06)	220	See Note 2	See Note 3
0.040/0.043		1.2 (±0.14)	440		
0.060/0.066		2.4 (±0.27)	800		
0.067/0.075		3.7 (±0.43)	1,100		
0.080/0.088		4.8 (±0.56)	1,500		
0.113/0.125		9.4 (±1.1)	3,000		

NOTES:

1. Aerostrand is constructed from "S" glass fiber reinforced with epoxy resin.
2. Aerostrand is in a research and development stage. Quantities are available for test purposes. Tapered construction is available by splicing different sizes of Aerostrand.
3. Production prices not available at this time. Prices quoted upon request.
4. The minimum bend diameter should be 140 times the nominal tension member diameter. Under certain conditions, a smaller working diameter may be used; however, adjustment in stress and safety factor must be made.
5. Physical properties are as follows:
   (a) Tensile Modulus - 7.0×10^6 psi at 72°F - 50% RH
   (b) Specific gravity - 1.93 (±0.17)
   (c) Elongation at Break - 5% at 72°F - 50% RH
   (d) Conduction - Greater than 500,000 ohms/ft with d-c or a-c current

Table XIX. Packard-Electric Tethers

Part No.	Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet) See Note 2	Cost per 100 Feet (dollars) See Note 3
GLASTRAN, PE-800						
65052-R	0.125/0.131	1 x 7	9.5	1,800	9,000	7.00
65053-R	0.188/0.198	1 x 19	22.0	3,800	5,000	16.00
65067-R	0.218/0.228	1 x 19	26.0	5,200	6,000	23.00
65055-R	0.312/0.332	7 x 7	57.0	10,000	6,000	48.00
65056-R	0.375/0.395	7 x 7	80.0	13,000	4,500	64.00
65057-R	0.438/0.468	7 x 19	110.0	17,500	3,000	95.00
65058-R	0.500/0.530	7 x 19	140.0	20,400	2,500	115.00
65060-R	0.625/0.655	7 x 19	218.0	32,000	6,000	175.00
65062-R	0.750/0.790	7 x 37	312.0	45,000	4,000	220.00
65064-R	0.875/0.915	7 x 37	445.0	62,000	5,000	280.00
65066-R	1.000/1.040	7 x 37	565.0	74,000	5,000	315.00

Table XIX. Packard-Electric Tethers (Continued)

Part No.	Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet) See Note 2	Cost per 100 Feet (dollars) See Note 3
GLASTRAN, PE-800-J (JACKETED)						
65072-R	0.149/0.167	1 x 7	13.0	1,800	9,000	9.00
65073-R	0.212/0.234	1 x 19	27.0	3,800	5,000	18.00
65087-R	0.242/0.264	1 x 19	32.0	5,200	6,000	24.00
65075-R	0.330/0.368	7 x 7	66.0	10,000	6,000	52.00
65076-R	0.399/0.431	7 x 7	90.0	13,000	4,500	67.00
65077-R	0.470/0.516	7 x 19	126.0	17,500	3,000	100.00
65078-R	0.532/0.578	7 x 19	160.0	20,400	2,500	125.00
65080-R	0.657/0.703	7 x 19	240.0	32,000	6,000	180.00
65082-R	0.800/0.860	7 x 37	355.0	45,000	4,000	245.00
65084-R	0.925/0.985	7 x 37	490.0	62,000	5,000	315.00
65086-R	1.050/1.100	7 x 37	620.0	74,000	5,000	350.00

NOTES:

1. Gastran glass fiber cable is constructed of continuous filaments of high-strength "E" glass impregnated with epoxy resin. Filaments are assembled into strands and then constructed similar to rope. Electrical conductors can be incorporated upon request.

2. Special sizes and lengths are available on special order with an increase in price.

3. Prices listed were provided at time of publication; prices are OEM and for engineering estimates only.

4. Recommended minimum sheave and drum diameters should be 30 times the bare tether diameter.

5. Physical properties can be obtained from manufacturer. Elongation curves are given in Figures 51 and 52, shown earlier in this section.

Table XX. Samson Cordage Works Tethers

Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) See Note 5
BRAIDED NYLON (See Note 1)					
0.25	2-in-1	16.6	2,100	600 (See Note 4)	5.23
0.312		27.8	3,500		8.62
0.375		33.3	4,200		10.00
0.437		50.0	6,000		14.25
0.500		66.7	7,500		19.00
0.562		83.3	9,500		23.32
0.625		111.0	12,000		29.97
0.750		150.0	17,000		38.25
0.875		208.0	23,700		52.00
1.000		250.0	28,500		61.25

Table XX. Samson Cordage Works Tethers (Continued)

Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) (see Note 5)
POWER BRAID (See Note 2)					
0.25	2-in-1	16.6	2,100	600 (See Note 4)	5.23
0.312	↓	27.8	3,500		8.62
0.375		33.3	3,400		8.75
0.437		50.0	5,000		12.50
0.500		66.7	7,400		16.50
0.562		83.3	8,600		20.75
0.625		111.0	11,500		25.92
0.750		150.0	16,000		36.00
0.875		208.0	20,800		48.00
1.000		250.0	25,000		60.00
STABLE BRAID (See Note 3)					
0.25	2-in-1	17.0	1,700	600 (See Note 4)	7.23
0.312	↓	26.0	2,600		10.40
0.375		35.0	3,500		13.83
0.437		51.0	5,100		19.13
0.500		68.0	6,800		24.82
0.562		110.0	11,000		39.60
0.625		150.0	15,000		51.00
0.750		200.0	20,000		68.00
0.875		280.0	28,000		95.20
1.000		350.0	35,000		112.00

NOTES:

1. Braided nylon - braided nylon cover, braided nylon center.
2. Power braid - braided nylon cover, braided polypropylene center.
3. Stable braid - braided polyester cover, braided polypropylene center.
4. Longer lengths are abailable by request.
5. List price from manufacturer.
6. Sheave and drum diameter should have a minimum ratio of 15 to 1, based on tether diameter.
7. Elongation characteristics are given in Figure 53, shown earlier in this section.
8. Dielectric properties and physical characteristics are available from manufacturer.

Table XXI. United States Plastic Tethers (Mylar)

Diameter (inches)	Design Construction	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet) See Note 2	Cost per 100 Feet (dollars)
0.125	See Note 1	6.67	500	5,000	12.00
0.156		9.10	685	4,000	16.00
0.187		15.6	1,050	2,500	20.00
0.250		21.3	1,400	2,500	33.00
0.312		30.3	2,100	1,725	47.00
0.375		41.7	2,750	1,200	60.00
0.437		60.2	3,980	1,200	89.00
0.500		83.5	5,200	600	121.00
0.562		100.0	6,000	600	175.00
0.625		139.0	6,750	600	---
0.750		167.0	10,000	600	262.00
0.875		238.0	15,500	600	324.00
1.000		278.0	18,500	600	414.00

NOTES:

1. Rope is manufactured from DuPont polyester film 3/4" wide by 0.001" (1 mil) thick. The film is formed into thread by the patented process of U.S. Plastic Rope. Construction is in conventional 3-strand in either regular twist (standard lay) or low twist (long lay).

2. All sizes available in unbroken coils up to 2,500 feet on special order. Prices for jacketed and braided ropes available on request.

3. Use a minimum sheave or drum diameter of 10 times the tether diameters.

4. Physical characteristics are available from manufacturer.

Table XXII. United States Steel Tethers

Diameter (inches)	Design Construction See Note 1	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) See Note 3
AMGAL-MONITOR AA ROPE					
0.156	3 x 7	40.2	2,800	See Note 2	4.62
0.172	↓	48.6	3,300		4.88
0.187	↓	57.3	3,900		5.03
0.218	↓	73.8	5,000		6.40
0.250	↓	97.2	6,600		7.76
0.312	↓	147.0	10,000		8.83
0.375	↓	213.0	14,500		9.90
0.437	↓	284.0	19,300		16.20
0.500	↓	375.0	25,500		17.20
0.562	↓	478.0	32,500		20.70

Table XXII. United States Steel Tethers (Continued)

Diameter (inches)	Design Construction See Note 1	Weight per 1000 Feet (pounds)	Minimum Breaking Strength (pounds)	Standard Shipping Length (feet)	Cost per 100 Feet (dollars) See Note 3
AMGAL-MONITOR AA ROPE (Continued)					
0.172	3 x 19	50.7	3,500	See Note 2	5.57
0.187		58.6	4,000		6.68
0.218		79.5	5,400		7.67
0.250		99.7	6,750		10.65
0.312		153.0	10,300		11.97
0.375		220.0	14,800		13.90
0.437		304.0	20,000		19.09
0.500		392.0	25,700		20.90
0.562		492.0	32,500		23.00
0.625		602.0	40,300		28.90
0.750		879.0	57,800		42.30
0.875		1210.0	78,000		52.30
1.000		1560.0	100,600		64.70
STAINLESS STEEL TYPE 304					
0.156	3 x 7	40.6	2,800	See Note 2	10.48
0.172	3 x 7	49.1	3,300		11.96
0.187	3 x 7	57.8	3,900		13.45
0.218	3 x 7	74.5	5,000		18.24
0.172	3 x 19	51.2	3,500		14.50
0.187	3 x 19	59.2	4,000		17.08
0.218	3 x 19	80.3	5,400		21.63
0.250	3 x 19	100.6	6,750		26.20
STAINLESS STEEL TENELON					
0.375	3 x 19	221.0	12,700	See Note 2	See Note 4
0.437	3 x 19	299.0	17,200		
0.500	3 x 19	388.0	22,000		
0.562	3 x 19	487.0	28,000		

1. If more flexibility is required, a 3 x 46 may be ordered in the following sizes: 0.625, 0.750, 0.875, and 1.00.
2. Standard shipping lengths of 30,000 feet are available for sizes less than 0.25 inch. Longer lengths are available in the smaller sizes.
3. Prices listed were provided at time of publication; prices are OEM and for engineering estimates only.
4. Prices for the Tenelon ropes are approximately 5% higher than the Type 304 stainless steel rope.
5. An approximate value of 40 times the diameter should be used for sheave and drum diameters.
6. Custom-made tethers are available by contacting manufacturer. Higher breaking strengths are available upon request.
7. USS non-rotating ropes have an elevated elastic limit as compared to conventional six-strand rope. Elongation information is available upon request.

(Page 122 is blank)

SECTION VI

BALLOON HANDLING

1. GENERAL

Any balloon system operation is a series or sequence of individual steps, necessitating throughout a total operation certain inspection and monitoring requirements.

Paragraph 2 presents general and rather universal cautionary instructions. The flow charts following paragraph 3 present a nearly universal flow diagram.

2. BALLOON HANDLING PRECAUTIONS

There are several precautions to exercise in the handling of balloons. While the envelope material is strong and durable in many respects, it must be handled with care. Personnel should be instructed in careful handling techniques and required to trim fingernails, remove sharp cornered rings, watches, and pencils from breast pockets, etc. The handling technique precautions are listed below.

(1) Hold and lift or pull the balloon with both hands in a flat open position.

(2) Do not grab balloon with fingers and/or pull with fingertips.

(3) Do not step or kneel on the balloon.

(4) Do not smoke near the balloon.

(5) Do not wrap the rope around body, hands, or feet.

(6) Do not put patches in peel. Pull "in line" with the patch.

(7) Pick up sharp objects (stones, bricks, boards, etc) on the ground before laying out the ground cloth.

(8) Do not lay the balloon on sharp or protruding objects.

(9) Keep the area "picked up."

(10) Keep feet out of line entanglements.

(11) Be sure all lines are free of knots, twists, and each other.

(12) Protect the balloon from abrasion at all times. Keep it wrapped in protective cloth and in the box when stored.

(13) Do not step over tether line between winch and pulley assembly.

3. BALLOON SYSTEM OPERATIONS

The wide variety of balloon systems precludes detailing the operational procedures of each. Moreover, specific procedures change with experience of individual operators. However, it is possible to set forth in general terms the functions required of all balloon systems - large or small, simple or complex. Specific operating details of a system would be furnished by the supplier.

The format chosen for outlining balloon operations has been borrowed, with some license, from the functional flow diagrams of system engineering procedures. This format was

chosen as presenting the clearest picture of balloon operations. It also may be expanded by the reader to detail a particular balloon system that may be under consideration.

The functional diagrams, which are shown in Figures 67 through 74, are sequence oriented but not time oriented. They normally flow from left to right. The gross functions are expanded one level and show some of the differences among the various systems. Function blocks are numbered for identification only, not to indicate sequence.

Several functions are shown preceded by or followed by "AND," which denotes that all these functions must be performed, but not in a particular sequence, prior to proceeding to the next function.

Functions or a sequence of functions preceded by or followed by "OR" denotes more than one method of accomplishing a function or that more than one type of equipment may be used to perform the function.

A line marked "G" (no-go) from the bottom of a functional block indicates where something may go wrong which must be corrected before proceeding.

Monitoring functions, such as weather or balloon pressure, are shown at the top or bottom of a diagram. A vertical line from the mainflow line shows the start of a monitoring function, which continues until another vertical line returns to the mainflow line - often through several diagrams.

The system diagrammed is a composite one, in some cases showing more than one type of equipment through the use of "OR." Thus the differences may be shown in their proper relative position in the balloon operation.

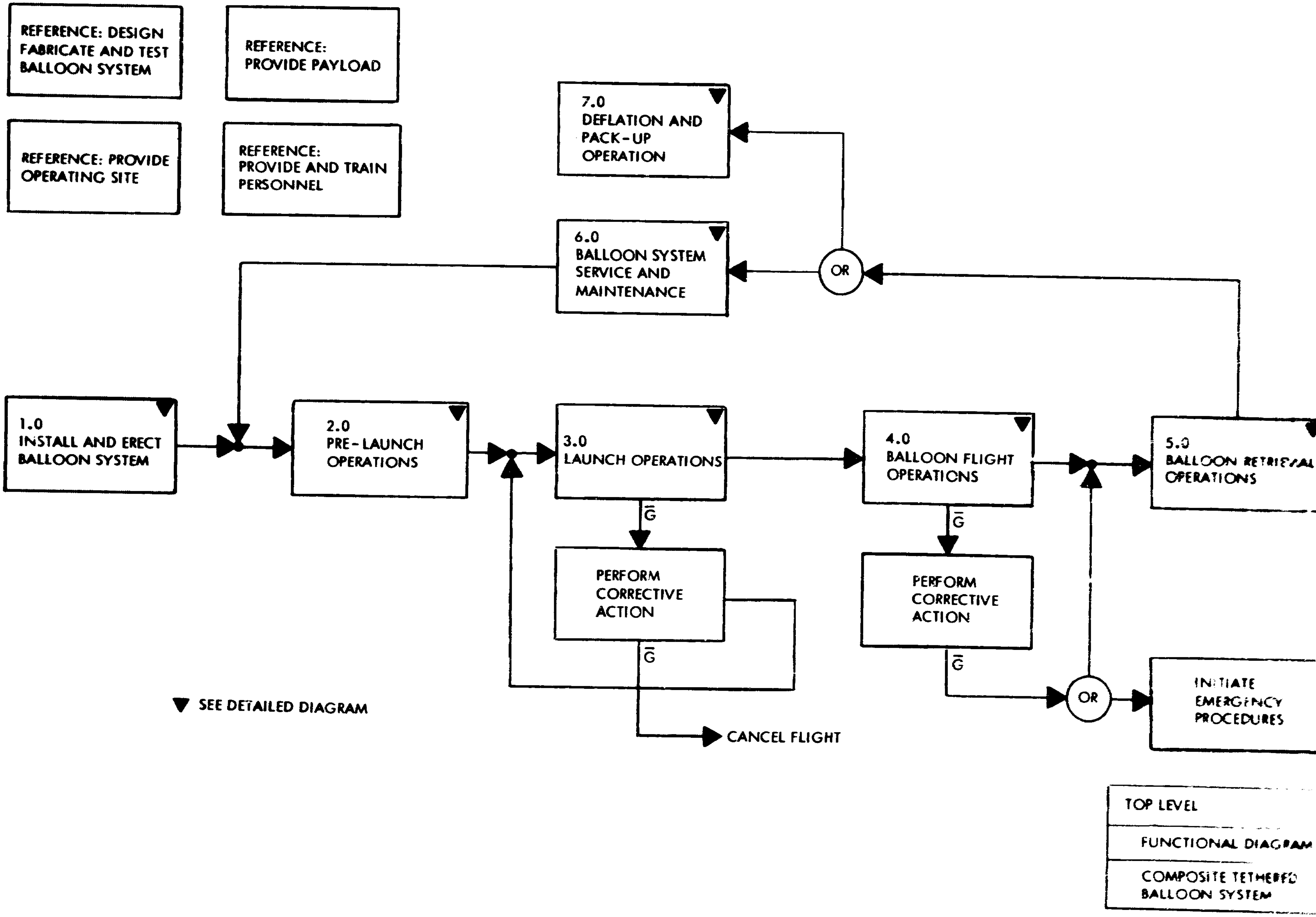


Figure 67. Balloon Handling Functional Breakdown

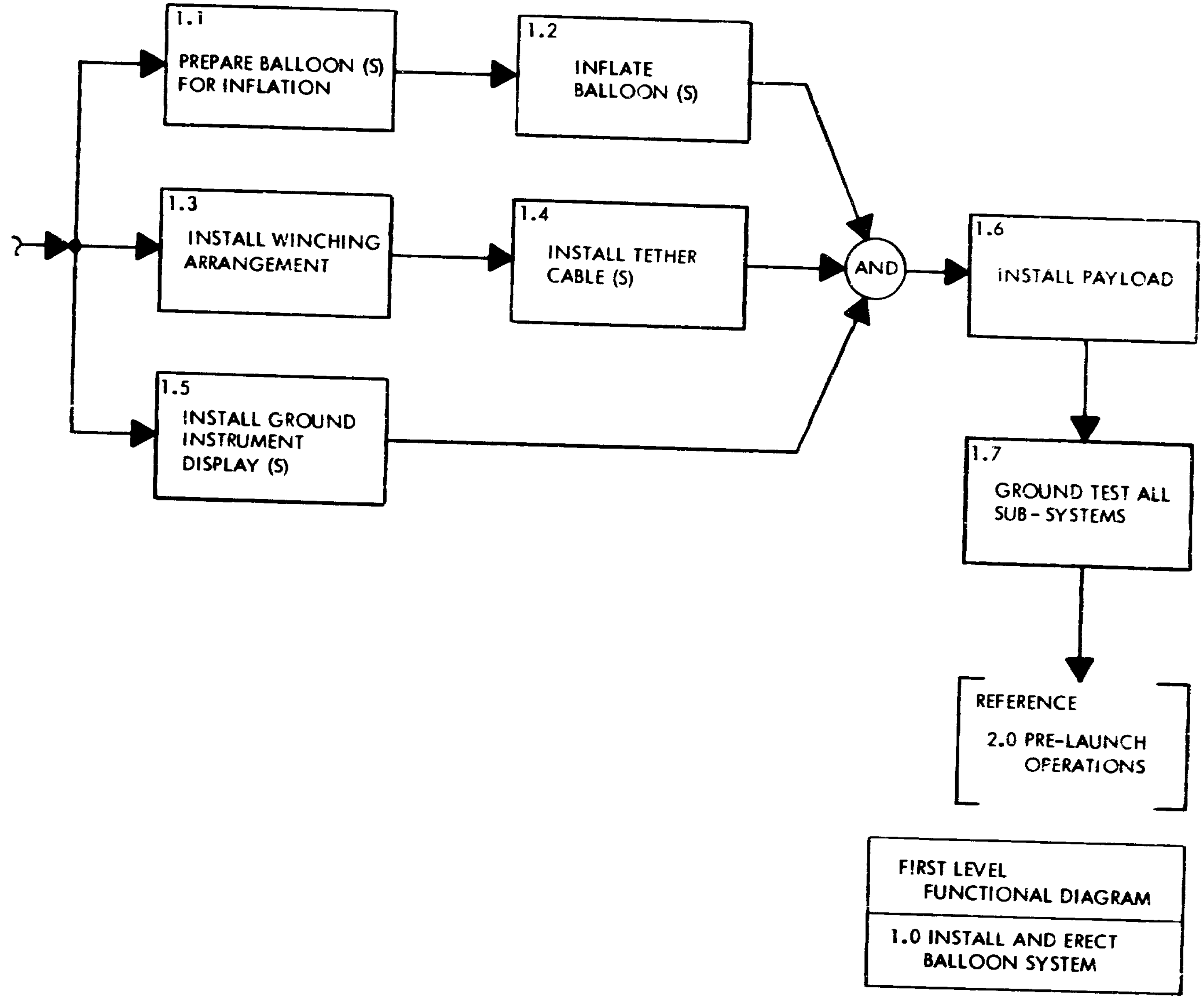


Figure 68. Installing and Erecting Balloon

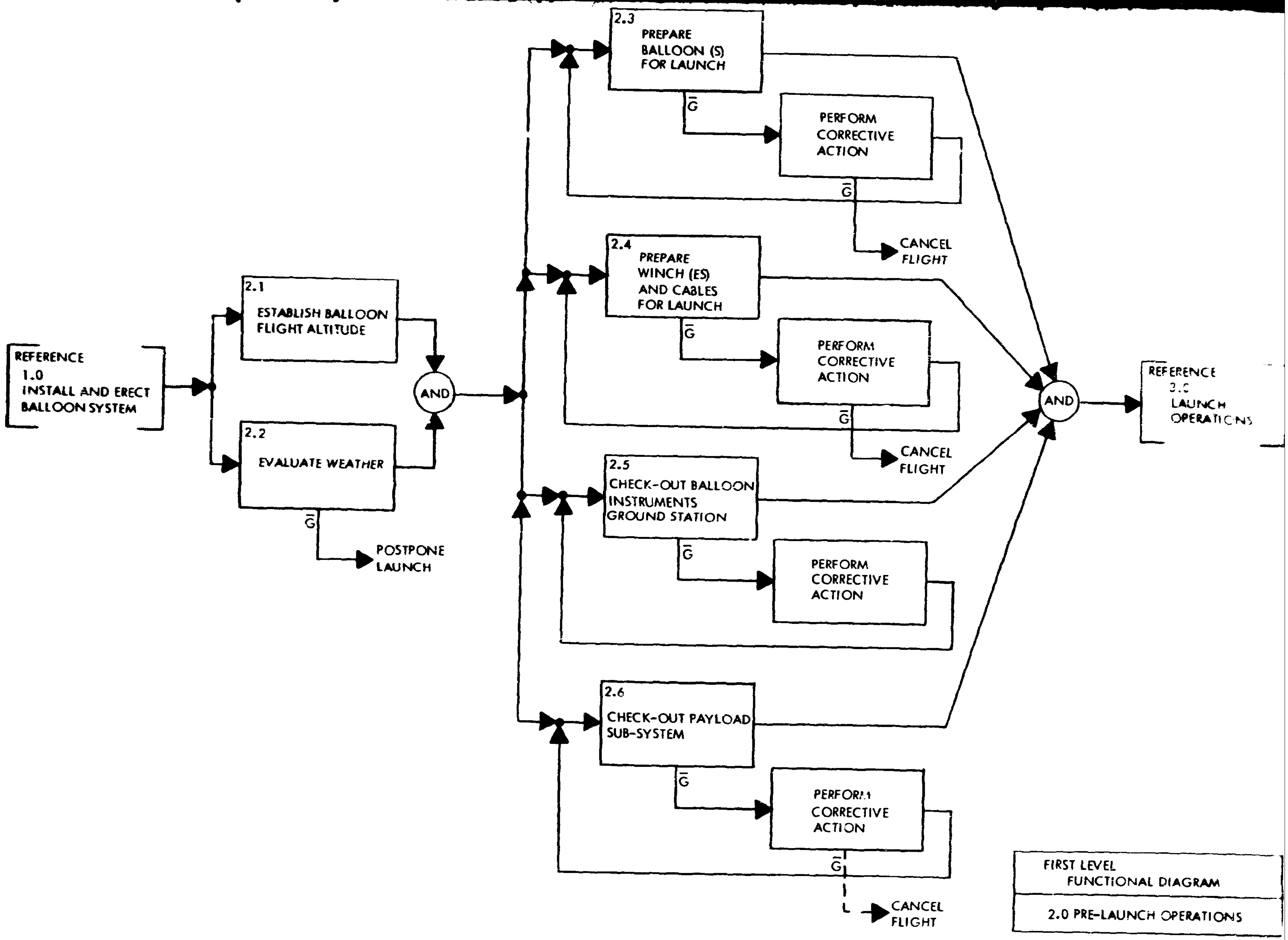


Figure 69. Prelaunch Operations

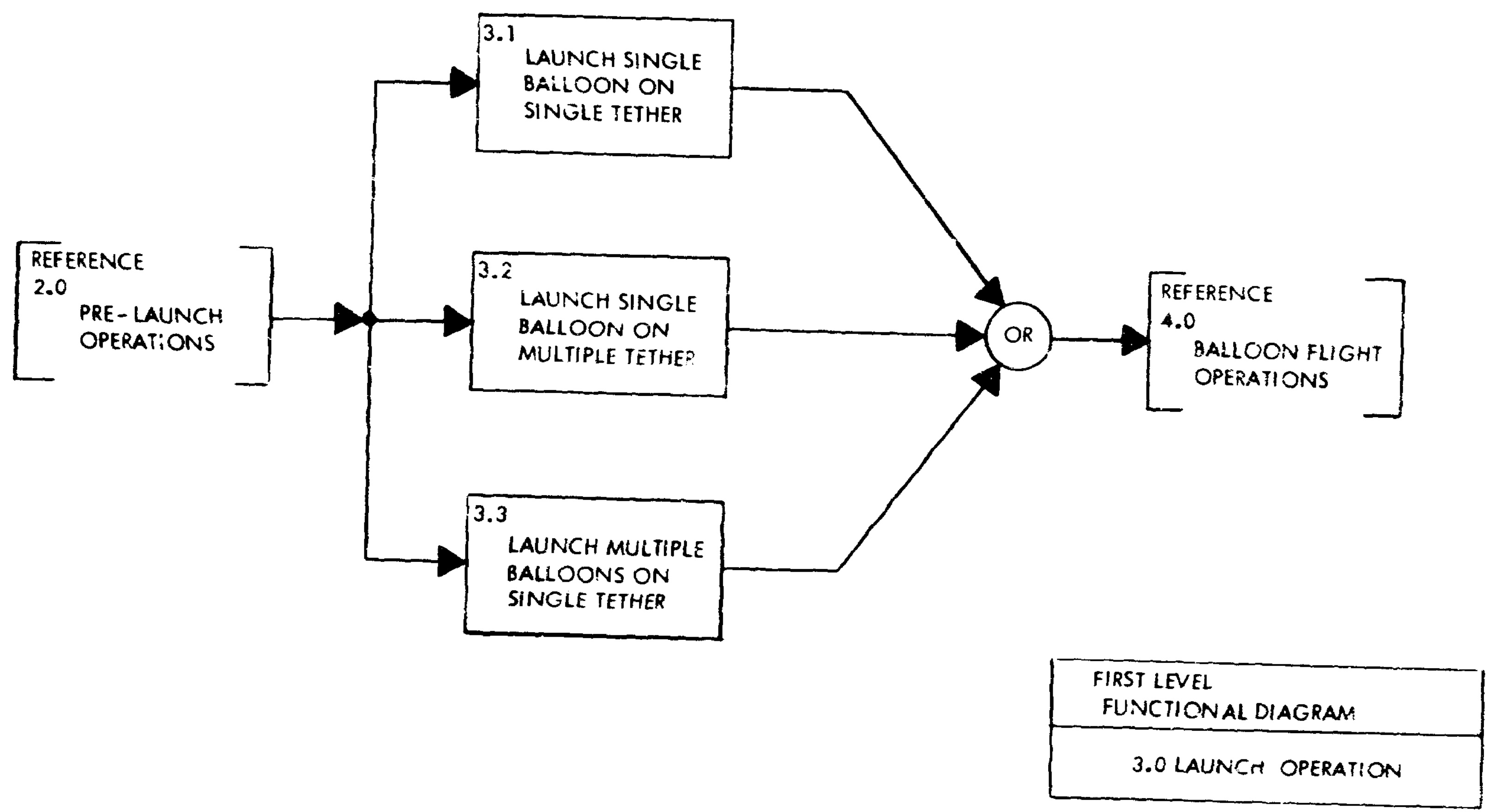
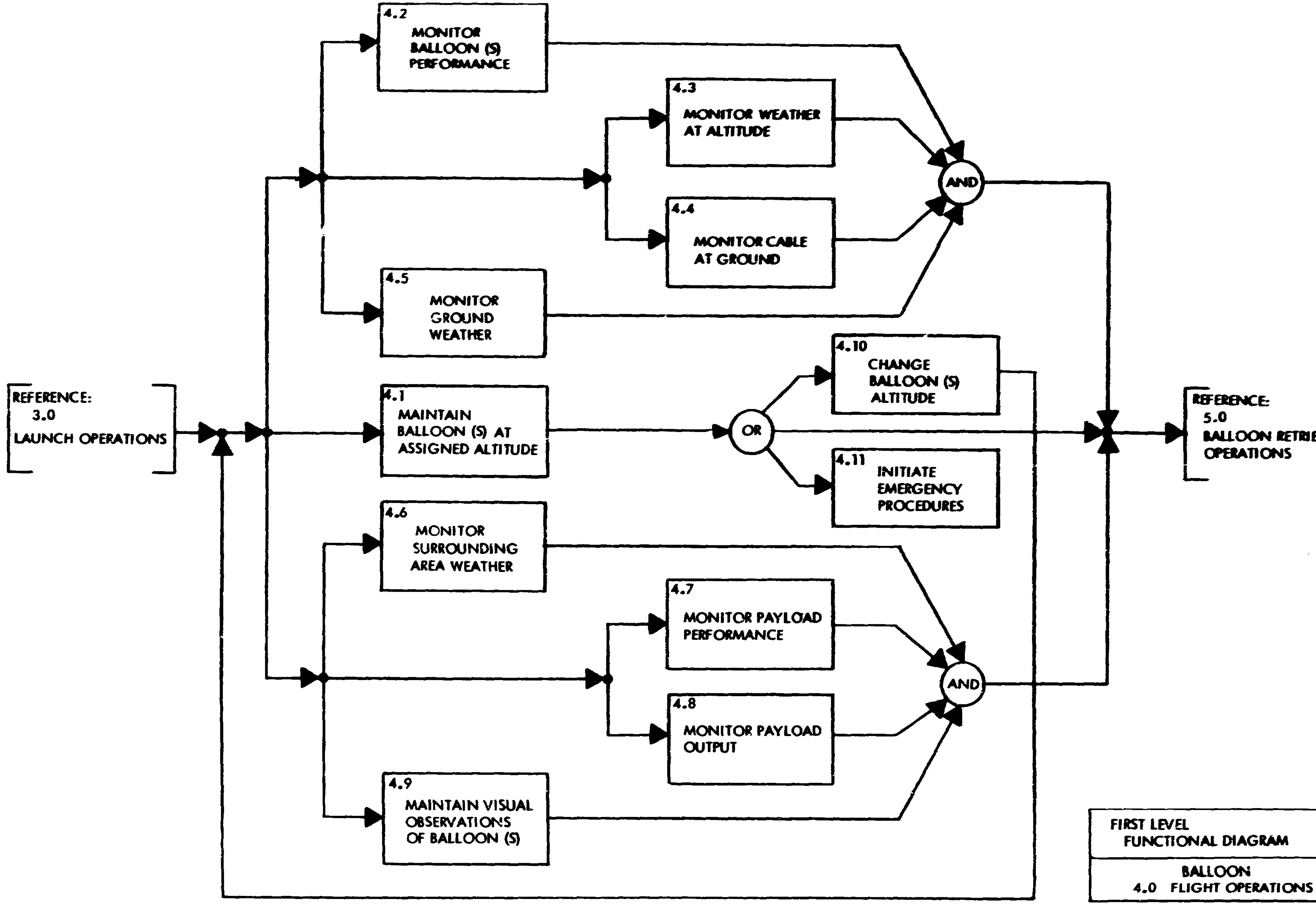


Figure 70. Launch Operations



FIRST LEVEL FUNCTIONAL DIAGRAM
BALLOON 4.0 FLIGHT OPERATIONS

Figure 71. Balloon Flight Operations

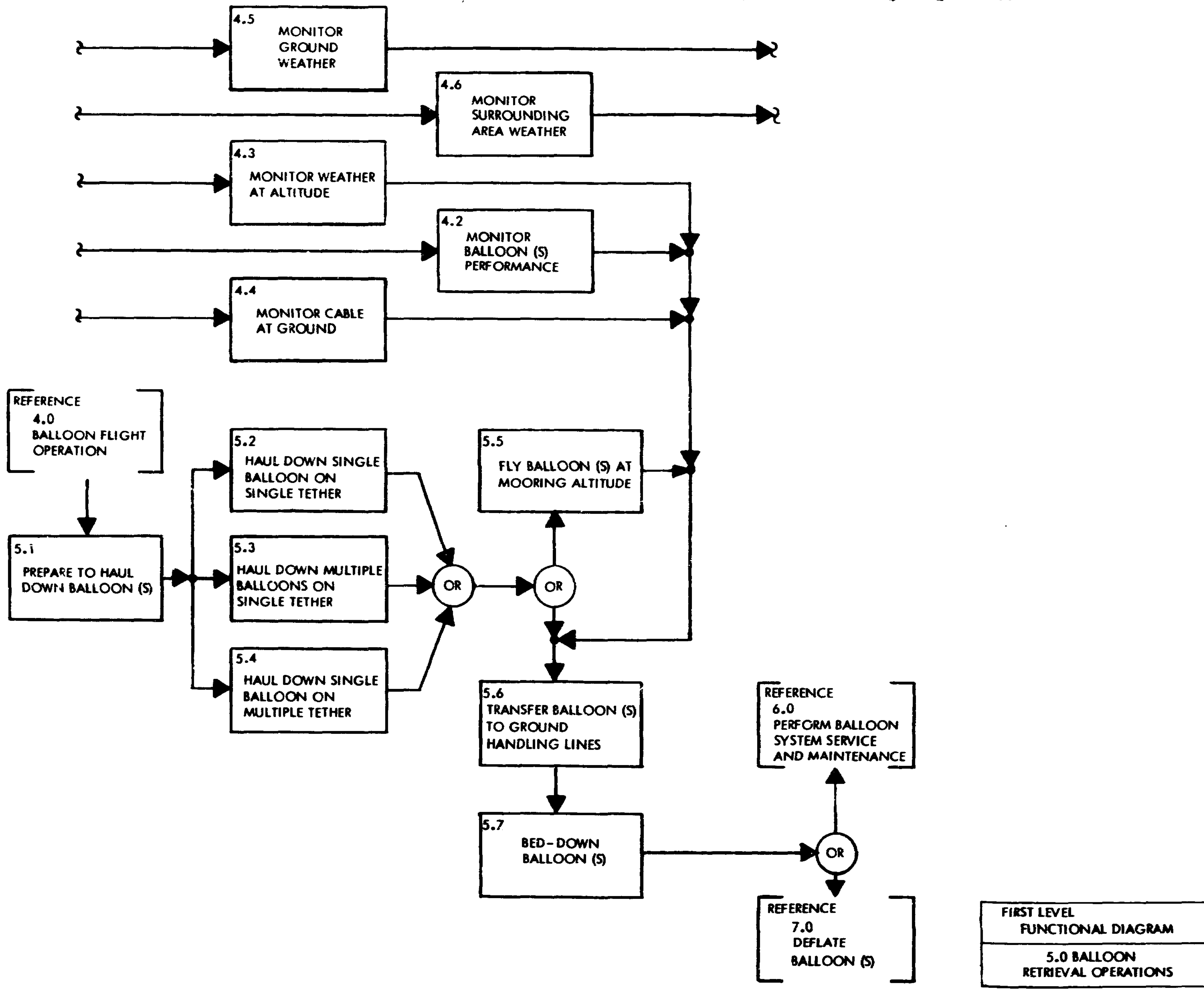


Figure 72. Balloon Retrieval Operations

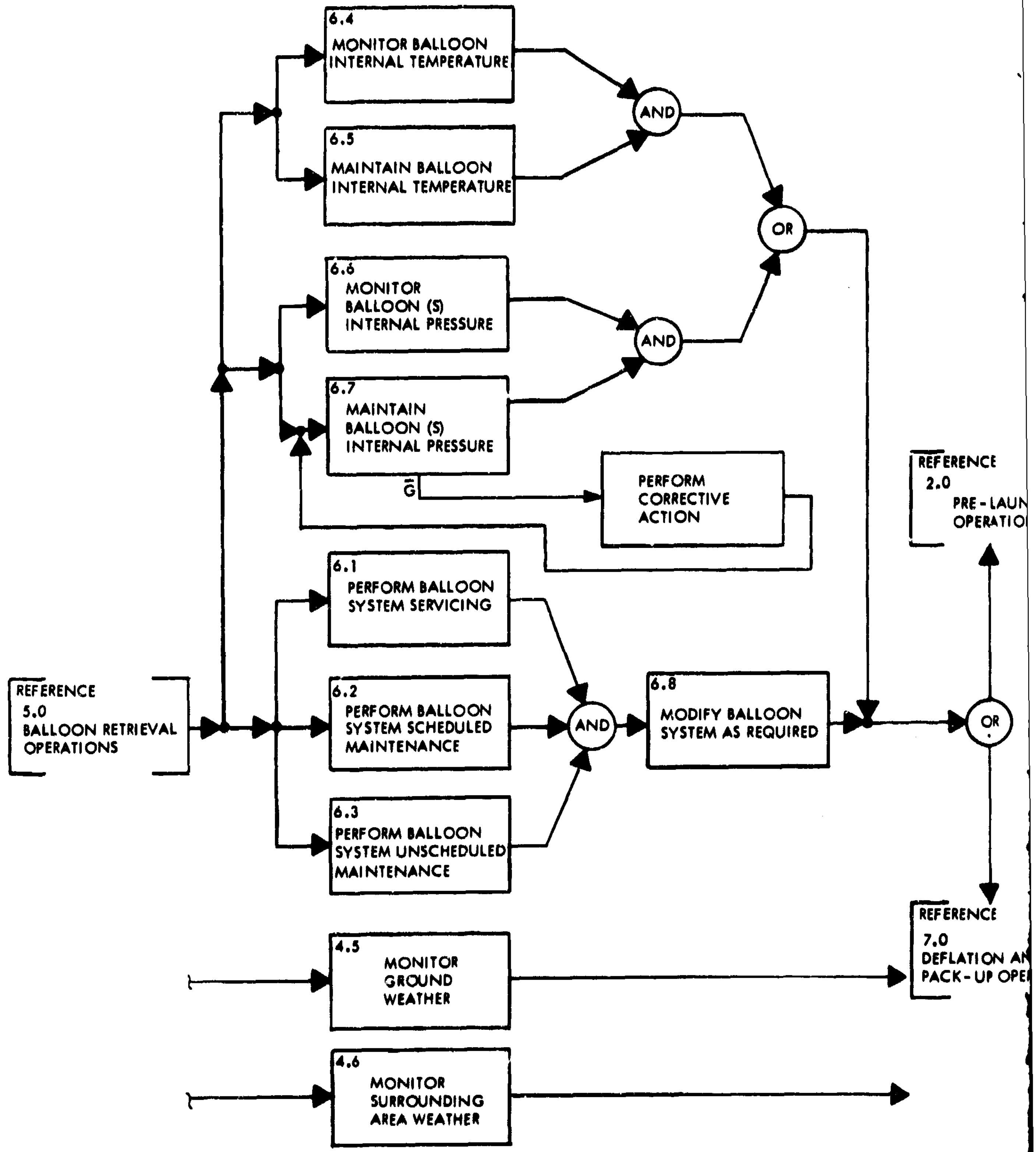
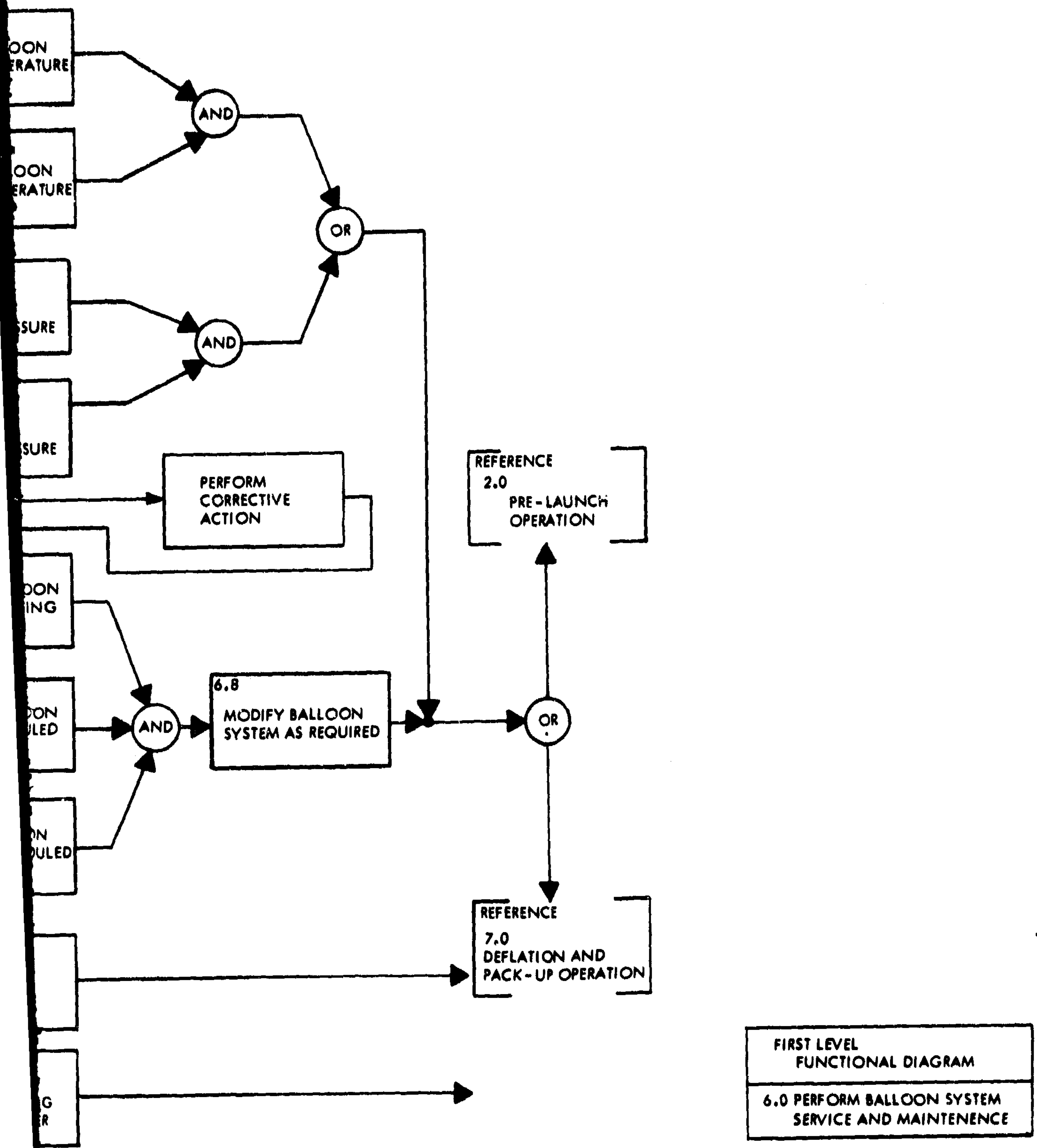


Figure 73. Balloon System Service and Maintenance Operations



re 73. Balloon System Service and Maintenance Operations

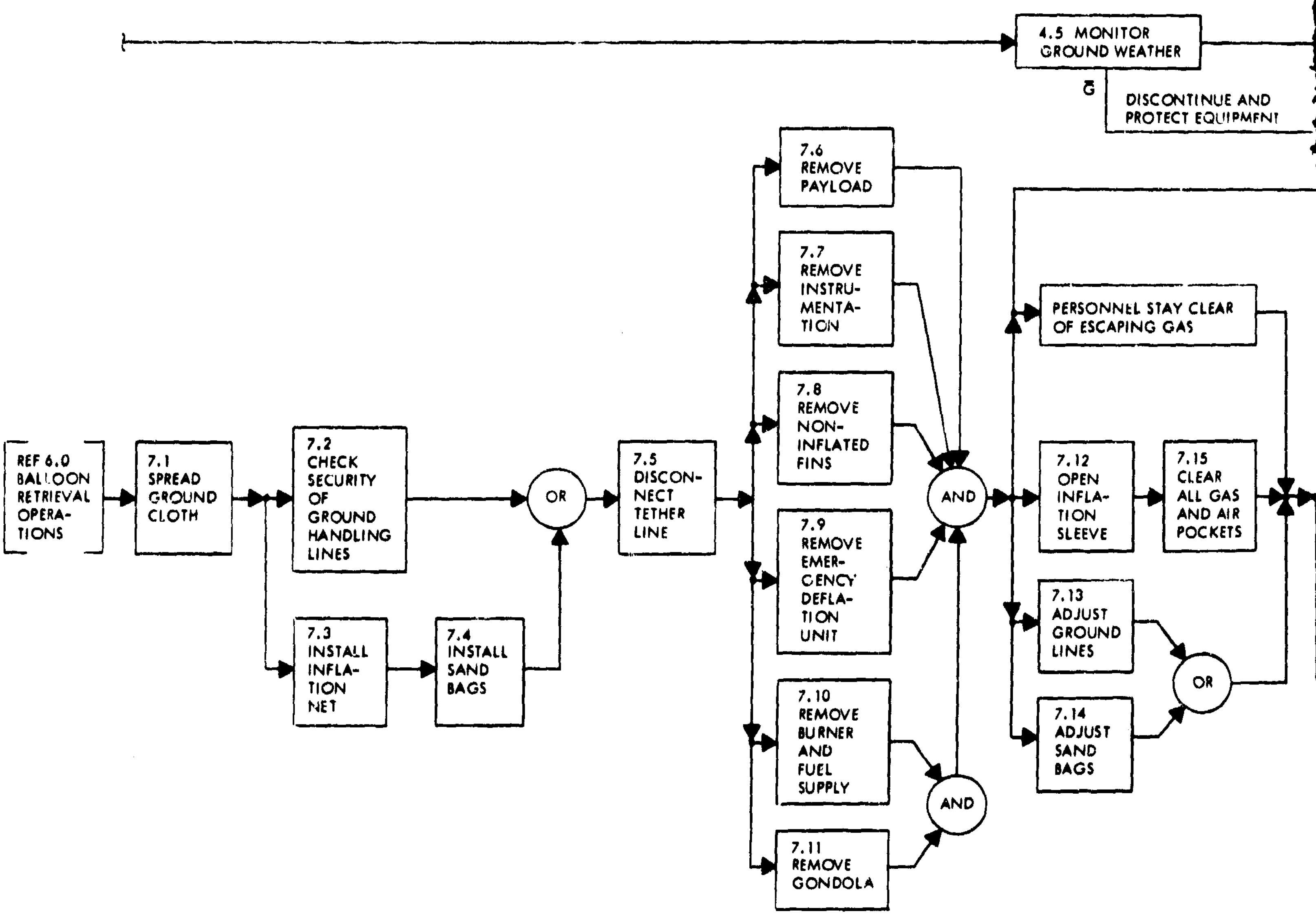
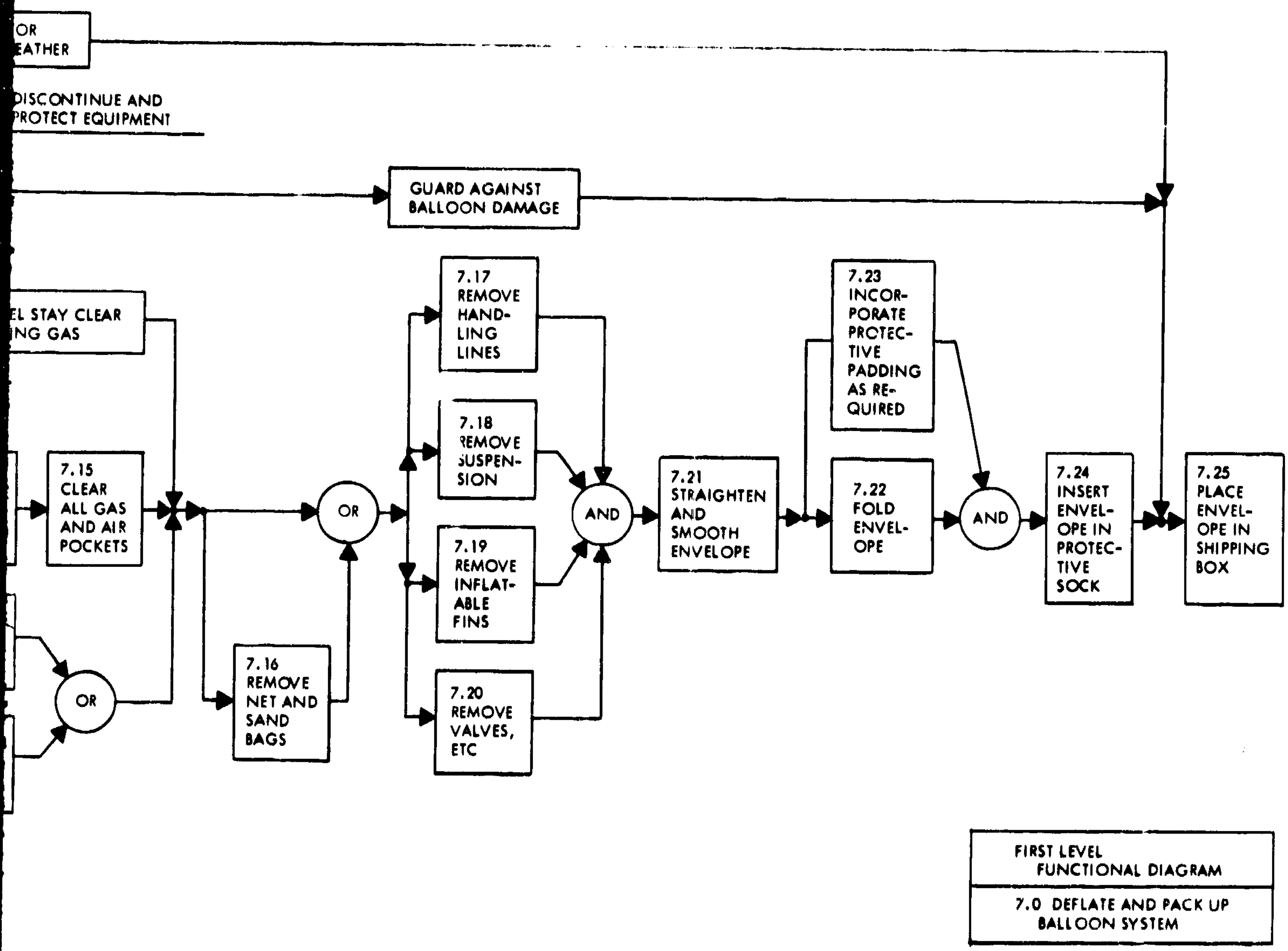


Figure 74. Deflation and Pack-Up Op

A



tion and Pack-Up Operations

B

SECTION VII

INSTRUMENTATION

1. GENERAL

Instrumentation for tethered balloons will vary considerably with each specific application. Two of the main factors to be considered are the altitude at which the balloon will be flown and the duration of the flight. For high-altitude flights, Telemetry systems with self-contained power supplies should be considered to eliminate the excessive weight of power and signal cables. If these high-altitude flights are to be of long duration, command control systems should be considered to turn the telemetry system on and off for data acquisition at infrequent intervals. However, if the balloons are at a lower altitude, power and signal cables can be strung in the tethering line, and conventional excitation can power supplies, signal amplifiers, and recording devices.

This document does not intend to design the complete instrumentation system involved in gathering the specific data depicting balloon performance. Tables XXIII through XXVIII define a majority of the measuring instruments available for determining the balloon performance. The manufacturers of these instruments manufacture their own specific brand of transducer excitation, signal amplifiers, and recorders. Many combine these three elements into one unit, and others make them as separate components. The readout equipment can be either visual or recorded. Most instruments can be used with available conventional equipment. Setup of the systems can be quite simple or very complicated, depending on the specific application.

The instruments being considered to cover most applications are temperature sensors, pressure transducers, accelerometers, load cells, and wind direction and wind speed indicators. The instruments referred to in Tables XXIII through XXVIII are in the ranges of tethered balloon uses. All values listed are nominal and may not apply to each specific manufacturer listed. The cost of the components listed in these tables varies with each specific type and manufacturer. A brief description of each transducer's operation is listed in the tables. The instrumentation manufacturers are listed in Table XXIX.

2. TEMPERATURE SENSORS

Temperature sensors break down into three categories - thermocouples, thermistors, and resistance. Thermocouples are a temperature-sensitive junction of two metals that generate an E.M.F. as a function of the temperature. This is a small millivolt output. This signal must be run to the recording device with special thermocouple wire or be transferred to a copper lead wire in a controlled reference junction. Thermistors and resistance thermometers operate on the principle of a change in resistance to the element due to change in temperature. The output of thermistors and resistance thermometers is usually in millivolts. Signals from all of these sensors must be amplified if they are a long distance from the recorder. All three types can be manufactured in many forms to withstand any environment. (Refer to Table XXIII.)

3. PRESSURE TRANSDUCERS

Pressure transducers measure in three basic forms - absolute pressure, gauge pressure, and differential pressure. Almost all manufacturers make transducers in all three forms. However, the principle on which they work varies considerably. First there is a bellows or diaphragm that physically moves when pressure is applied. This movement in turn excites a signal in one of several signal systems, such as a strain gauge, solid-state device, potentiometer, or variable reluctance device. Another system is the bourdon tube which turns and thus moves a coil in a fixed field or moves a wiper on a potentiometer. Another type is the pressure capsule which is similar to a diaphragm except that is has considerably more motion. One other type that is not listed in Table XXIV is the piezoelectric type that is self-generating of a signal. Most of these, however, fall in a pressure range above that compatible with tethered balloons.

4. ACCELEROMETERS

Inertia forces in a specific direction are measured by accelerometers. Alignment of the sensitive axis of the sensor at installation determines the response direction. Three independent accelerometers are sometimes assembled with the individual axes orthogonal to each other. In all cases the acceleration is determined by measurement, either directly or indirectly, of the force on a mass of known value. Strain gauges or potentiometers requiring deflection (which results in inherent errors) are used in the simplest form of this sensor. Piezoelectric crystals are used as a force-measuring device and require very slight deflections. The response of these crystals is such that they are most effectively used in the measurement of high accelerations or in applications where d-c response is not required.

The mass element within an accelerometer is damped by means of entrapped gas or liquid to provide a specified response to stimulus. When the acceleration to be measured is known to be only low frequency, deflection errors are eliminated through the use of a servo-null system. (Refer to Table XXV.)

5. LOAD CELLS

Load cells are generally of the strain gauge type; however, there are other types available (refer to Table XXVI). Manufacturers have standard off-the-shelf configurations that meet most requirements. They also manufacture these load cells in any requested configuration. For cable tensions, the cable can be split and the strain link inserted in the cable, or the strain link can be connected to pulleys that support the cable to measure the load in that manner. There are also devices that can be attached directly to a loaded cable for direct reading of load or transmission of a signal to a recorder.

6. WIND SPEED AND DIRECTION

Wind direction indicators are normally vane operated and the signal generated by means of a continuous potentiometer or synchronous a-c motor (refer to Table XXVII). They are normally mounted from a ground tower, which provides a fixed and stable support.

Wind speed measuring devices, which can be balloon-mounted, include impact tubes (pitot) or anemometer cups driving a d-c generator (refer to Table XXVIII). The anemometer is more popular and is readily coupled to most recording systems.

Another basic sensor type measures air velocity as a function of cooling of a heated resistance coil from the air flow.

Table XXIV. Pressure Transducers

Instrument	Type	Range	Accuracy	Resistance (ohms)	Resolution	Excitation	Output	V
Bellows or diaphragm strain gauge	Absolute Gauge Differential	0 to 1 psia and up 0 to 1 psig and up 0.05 psid and up	0.25% FS to 5% FS, depending on range	120, 350. Others on request.	Infinite	5 to 28 volts ac or dc, depending on manufacturer	1 to 10 mv/v nominal	4, 9 26, 72, 95,
Bellows or diaphragm solid-state strain gauge	Absolute Gauge Differential	0 to 10 psia and up 0 to 10 psig and up ±2 psid and up	±0.25% FS and up, depending on range	200 nominal. Others available.	Infinite	3 vac or 3 vdc to 28 vdc, depending on manufacturer	5 mv to 5 vdc	11, 97
Bellows or diaphragm variable reluctance	Absolute Gauge Differential	0 to 0.2 psia and up 0 to 1 psig and up ±0.1 psid and up	±0.03% FS	---	Infinite	24 to 32 vdc at 25 ma	0 to 5 vdc	10, 2 76
Bellows or diaphragm potentiometer	Absolute Gauge Differential	0 to 5 in. H_2O and up 0 to 1 psig and up ±0.5 psid	1% FS 2% FS 2% FS	All ranges from 300 to 15,000 nominal.	0.3% 0.3% 0.3%	Any voltage desired	Depends on excitation	10, 1 77
Bourdon tube signal generator	Absolute Gauge Differential	0 to 10 psia and up 0 to 10 psig and up 0 to 10 psid and up	±0.25% FS ±0.25% FS ±0.25% FS		Infinite	0 to 5 vdc	0 to 5 vdc	28
Bourdon tube potentiometer	Absolute Gauge	0 to 10 psia and up 0 to 10 psig and up	1% FS 1% FS	1000 and up 1000 and up	0.25% FS 0.25% FS	Depends on system	Depends on excitation	10, 2 83
Pressure capsule potentiometer	Absolute Gauge Differential	0 to 1 psia and up 0 to 1 psig and up ±0.5 psid	±3% ±3% ±3%	500 and up	Infinite	Depends on system	Depends on excitation	10, 3
Pressure Capsule LVDT	Absolute Differential	0 to 0.15 psia and up ±0.15 psid and up	±0.15% ±0.15%		Infinite	Depends on system	Depends on excitation	68

*See list of manufacturers in Table XXIX.

A

Ta le XXIV. Pressure Transducers

istance ohms)	Resolution	Excitation	Output	Vendors[a]	Remarks
, 350. ers on uest.	Infinite	5 to 28 volts ac or dc, depending on manufacturer	1 to 10 mv/v nominal	4, 9, 18, 24, 26, 32, 56, 58, 72, 79, 80, 88, 95, 98	All manufacturers make a variety of half- and full-bridge transducers with low-level output, good reliability and repeatability. The bellows or diaphragm of metal bends under pressure, putting an unbalance in the strain gauge which is part of a four-arm Wheatstone bridge.
nomi- Others lable.	Infinite	3 vac or 3 vdc to 28 vdc, depending on manufacturer	5 mv to 5 vdc	11, 48, 68, 72, 97	Miniature and subminiature transducers withstand severe environmental conditions. Operation same as for strain gauge.
--	Infinite	24 to 32 vdc at 25 ma	0 to 5 vdc	10, 23, 45, 51, 76	High level input and output, suited for severe environments, high accuracy under extreme vibration. This type uses a variable reluctance displacement to voltage converter.
anges 300 ,000 inal.	0.3% 0.3% 0.3%	Any voltage desired	Depends on excitation	10, 14, 16, 68, 77	Simple design, high reliability and performance. This type usually moves the potentiometer wiper arm through a mechanical advantage.
	Infinite	0 to 5 vdc	0 to 5 vdc	28	Long-term stability, good safety on burst pressure. As the bourdon tube twists, it moves a coil in a fixed field, generating a new signal.
and and	0.25% FS 0.25% FS	Depends on system	Depends on excitation	10, 27, 73, 78, 83	Miniature, reliable. As the bourdon tube twists, it turns the wiper of a rotary potentiometer.
nd up	Infinite	Depends on system	Depends on excitation	10, 31, 34	Provides a large choice of operating voltages. Good linearity. As the pressure capsule expands, it moves the wiper arm of the potentiometer.
	Infinite	Depends on system	Depends on excitation	68	High degree of accuracy and reliability. As the pressure capsule expands, it moves the core through the windings of a linear variable differential transformer.

B

Table XXIII. Temperature Sensors

Instrument	Type	Range (°F)	Accuracy	Input Power	Output	Response	Vendors*	Remarks
Thermocouple	Iron-constantan	32 to 530 530 to 1400	±4°F ±3/4%	None	Millivolts	Very good	1, 3, 17, 19, 39, 41, 54, 60, 62, 63, 86, 95	Thermocouples are temperature-sensitive junctions of two metals that generate an E.M.F. as a function of its temperature. For optimum accuracy and sensitivity, the signal is usually amplified.
	Chromel-alumel	32 to 530 530 to 2300	±4°F ±3/4%	None	Millivolts	Very good		
	Copper-constantan	-150 to -75 -75 to +200 +200 to +700	±2% ±1-1/2°F ±3/4%	None	Millivolts	Very good		Thermocouples have a broad range with low sensitivity. They have good stability and repeatability.
	Chromel-constantan	32 to 600 600 to 1600	±3°F ±1/2%	None	Millivolts	Very good		
	Platinum-RH-platinum	32 to 1000 1000 to 2700	±5°F ±1/2%	None	Millivolts	Very good		All manufacturers make thermocouples in many forms: bare wire, probes, washer, miniature, special, in all lengths and diameters. Each manufacturer has his own special insulation and standard insulations. Cost varies with type, shape, and insulation.
Thermistors	Semi-conductor	Generally -40 to +300	±0.25°F	2 volts nominal	Up to 20 mv/°C	Very good	16, 17, 32, 43, 46, 61, 94, 95, 99	Temperature-sensitive thermistors change resistance as a function of temperature and cause a proportional unbalance in the circuit and a current flow through the meter or recorder. Thermistors have a narrow range with very high sensitivity, very good stability and repeatability.
Resistance	Platinum, nickel, balco, tungsten, copper	Generally -435 to +2000, as required	±0.1% to ±5%, depending on range	10 to 20 ma, depending on range	Millivolts	Good	18, 30, 53, 59, 65, 66, 69, 77, 85, 87, 89, 90, 93, 95	

*See list of manufacturers in Table XXIX.

Table XXVI. Load Cells

Instrument	Type	Range (lb)	Accuracy	Bridge Resistance (ohms)	Resolution	Excitation (vdc)	Outpu (mv/v
Strain gauge	Tension-compression	0 to 10 and up	0.25% FS	120 to 350, others on request	Continuous	5 to 28, depending on manufacturer	1.5 and u depending manufactu
Differential transformer	Tension-compression	±1 and up	0.5%	---	Continuous	2 to 30	5 to 20
Hydraulic tensiometer	Tension	0 to 1000 and up	---	---	---	---	---
Mechanical tensitron	Tension	0 to 1000 and up	---	---	---	---	---

*See list of manufacturers in Table XXIX.

Table XXVII. Wind Direction Transmitte

Instrument	Type	Range (degrees)	Accuracy (degrees)	Resistance (kilohms)	Excitation	Output	Ven
Potentiometer	Vane	360	±3	10 to 100, depending on manufacturer	12 vdc	0 to 4.8 vdc	7, 8, 12 20 35,
Synchronous a-c motors	Vane	360	±2	---	---	---	37

*See list of manufacturers in Table XXIX.

Table XXVIII. Wind Speed Transmitters

Instrument	Type	Range	Accuracy	Resistance (kilohms)	Excitation	Output	Vendo
Potentiometer	Anomometer cups	0 to 90 mph	±1%	10 and up	10.6 to 12.6 vdc	0.5 mw	16
D-c generator	Anemometer cups	0 to 100 mph	±1%	---	---	Self-generating	7, 8, 12, 2 37, 4 71
Thermopile	Tube	---	---	---	---	Self-generating	3, 38
Photo cells	Anemometer cups	0 to 100 knots	±1 knot	---	95 to 132 volts. Battery: 10.6 to 12.6 volts.	---	13
Pitot-static pressure	Tube	5 to 250 fps	1%		3 to 24 volts	Mv level	95

*See list of manufacturers in Table XXIX

Table XXVI. Load Cells

Bridge Resistance (ohms)	Resolution	Excitation (vdc)	Output (mv/v)	Vendors*	Remarks
120 to 350, others on request	Continuous	5 to 20, depending on manufacturer	1.5 and up, depending on manufacturer	9, 11, 15, 24, 42, 50, 52, 67, 80, 81, 88, 95	Usually a bar in tension or compression. Sometimes a cantilever type can cover large range.
	Continuous	2 to 30	5 to 20	21, 22, 25	Dual diaphragm. Spring attaches to a sensitive differential transformer.
				55	Attaches to cable with dial readout. No electrical output.
...	...	...	...	84	Attaches to cable; however, can be adapted to electrical readout by manufacturer.

Table XXVII. Wind Direction Transmitters

Resistance (kilohms)	Excitation	Output	Vendors*	Remarks
10 to 100, depending on manufacturer	12 vdc	0 to 4.8 vdc	7, 8, 12, 13, 16, 20, 35, 44, 71, 96	Uses low torque potentiometer.
...	...	...	37	One synchronous motor in vane and one in indicator equipment.

Table XXVIII. Wind Speed Transmitters

...racy	Resistance (kilohms)	Excitation	Output	Vendors*	Remarks
	10 and up	10.6 to 12.6 vdc	0.5 mw	16	Continuous rotary potentiometer puts out wave proportional to wind speed.
	...	...	Self-generating	7, 8, 12, 20, 35, 37, 44, 71, 96	D-c generator generally transmitting 360 pulses per revolution in digital output types and a d-c voltage in voltage types.
	...	...	Self-generating	3, 38, 95	Thermocouples are heated with an a-c current. A change in air flow changes the thermocouple temperature and d-c output.
...et	...	95 to 132 volts. Battery: 10.6 to 12.6 volts.	...	13	Light shining through a perforated disk on a photo cell gives a pulse-type signal.
	...	3 to 24 volts	Mv level	95	Air blowing over a heated resistance coil changes the resistance.

Table XXV. Accelerometers

Instrument	Type	Range	Accuracy	Bridge Resistance (ohms)	Resolution	Excitation	G
Strain Gauge	Linear	±0.25g and up	±1%	120 and 130	Infinite	5 to 28 volts ac or dc	4 to
Potentiometer	Linear Dual Axis Triaxial	±0.5g and up ±0.5g and up ±5g with ±2g in yaw	0.6% 1% 1%	1000 and up 500 and up 2000 and up	0.45% Varies with axis Varies with axis	Depends on system	Dep exci
Signal generator LVDT	Linear	±0.5g and up	1%	---	Continuous	28 volts ac or dc nominal	300 r
	Dual Axis	±1g each axis	1-1/2%	---	Continuous	28 volts ac or dc nominal	300 r
Servo balance nulling amp	Linear and multiaxis	±0.5g	0.01% FS	---	0.001% FS	±15 to 28 vdc	±7.5
Piezoelectric	Linear and multiaxis	±0.1g and up	±1%	---	0.01g max	None	1.5 (8.0 r depe on tr duce mate

*See list of manufacturers in Table XXIX.

Table XXV. Accelerometers

Bridge Resistance (ohms)	Resolution	Excitation	Output	Cross-Axis Error	Vendors*	Remarks
120 and 130	Infinite	5 to 28 volts ac or dc	4 to 10 mv/v	0.02g/g	5, 11, 18, 74, 80	Natural frequency varies with vendor and sensor. Bonded strain gauge in four-arm bridge attached to a cantilever.
1000 and up 500 and up 2000 and up	0.45% Varies with axis Varies with axis	Depends on system	Depends on excitation	0.01g/g 0.01g/g 0.02g/g	10, 27, 33, 40 40 33, 40	High reliability with low cross-axis error. Usually spring mass system with potentiometer coil. Both gas and liquid damped.
--- ---	Continuous Continuous	28 volts ac or dc nominal 28 volts ac or dc nominal	300 mv/v 300 mv/v	0.02g/g 0.015g/g between sensitive axis	27, 33, 49, 70, 92 33	These transducers have high sensitivity. Fluid or gas damped. This is usually a spring retained mass which is the core of the linear variable differential transformer.
---	0.001% FS	±15 to 28 vdc	±7.5 vdc max	0.002g/g	36, 47, 82	This is a miniature servo system. A mass movement causes unbalance of servos. The unbalance is detected and a nulling amp sends balancing current to restoring coil.
---	0.01g max	None	1.5 (min) to 8.0 mv/g, depending on transducer material	3% max	2, 6, 18, 29, 36, 47, 56, 57, 75, 91	There are three basic designs used in piezoelectrics: bending, compression, and shear. The piezoelectric material is usually quartz, ceramic, or similar man-made composites. A self-generating electrical charge is the result of pressure being applied to these materials and is proportional to the force being applied.

II

Table XXIX. List of Instrumentation Manufacturers

1. Aero Research Instrument Dept.
9000 King Street
Franklin Park, Illinois 60131

2. AGAC-Derritron Inc.
1332 N. Henry St.
Alexandria, Virginia 22314

3. Alnor Instrument Company
Division of Illinois Testing Laboratories, Inc.
420 North LaSalle Street
Chicago, Illinois 60610

4. American Standard Inc.
Monrovia Instrument Department
Advanced Technology Division
1401 S. Shamrock Avenue
Monrovia, California 91016

5. B & F Instruments, Inc.
Cornwells Heights, Pennsylvania 19020

6. B & K Instruments, Inc.
Bruel & Kjaer Precision Instruments
5111 West 164th Street
Cleveland, Ohio 44142

7. Beckman & Whitley Inc.
985 San Carlos Ave.
San Carlos, California

8. Belfort Instrument Company
4 North Central Avenue
Baltimore 2, Maryland

9. BLH Electronics, Inc.
Subsidiary of Baldwin-Lima-Hamilton Corporation
42 Fourth Avenue
Waltham, Massachusetts 02154

10. Bourns Inc.
Instrument Division
6135 Magnolia Ave.
Riverside, California 92506

11. Bytrex, Inc.
223 Crescent Street
Waltham, Massachusetts 02154

12. Cambridge Systems, Inc.
50 Hunt St.
Newton, Massachusetts 02158

13. Cardion Electronics
A Unit of General Signal Corporation
Long Island Expressway
Woodbury, New York 11797

14. C-E Electronics, Inc.
363 West Glenside Avenue
Glenside, Pennsylvania 19038

15. Celtic Industries, Inc.
14743 Oxnard Street
Van Nuys, California 91401

16. Climet Instruments, Inc.
1240 Birchwood Dr.
Sunnyvale, California 94086

17. Conax Corporation
2300 Walden Avenue
Buffalo, New York 14225

18. Consolidated Electrodynamics
1400 S. Shamrock Ave.
Monrovia, California 91016

19. Continental Sensing Inc.
1960 N. Ruby Street
Melrose Park, Illinois 60160

20. Control Equipment Corporation
19 Kearney Road
Needham Heights, Massachusetts 02194

21. Cresent Engineering & Research Co.
5440 North Peck Rd.
El Monte, California

22. Daytronic Corporation
2875 Culver Avenue
Dayton, Ohio 45429

23. The Decker Corporation
101 Monument Road
Bola-Cynwyd, Pennsylvania 19004

24. Dentronics, Inc.
60 Oak Street
Hackensack, New Jersey 07601

25. W.C. Dillon & Co., Inc.
14620 Keswick Street
Van Nuys, California 91407

Table XXIX. List of Instrumentation Manufacturers (Continued)

26. Dynisco
A division of Microdot Inc.
20 Southwest Park
Westwood, Massachusetts 02090

27. Edcliff Instruments
1711 So. Mountain Avenue
Monrovia, California 91016

28. ElectoSyn Technology Laboratories, Inc.
480 Neponset Street
Canton, Massachusetts 02021

29. Endevco Laboratories
A Division of Becton, Dickinson and Company
1675 Stierlin Road
Mt. View, California 94040

30. Eon Instrumentation Inc.
15547 Cabrito Road
Van Nuys, California 91406

31. Fairchild Controls
225 Park Avenue
Hicksville, L.I., New York 11802

32. General Transducer Co.
2961 Corvin Dr.
Santa Clara, California

33. Genisco Technology Corporation
18435 Susana Road
Compton, California 90221

34. Giannini Control Corp.
330 Madison Ave.
New York, New York

35. Henry J. Green Instruments Inc.
2500 Shames Drive
Westbury, Long Island, New York

36. Gulton Industries Inc.
1644 Whittier Ave., P.O. Box 2176
Costa Mesa, California 92627

37. W.&L.E. Gurley
514 Fulton Street
Troy, New York 12181

38. Hastings-Raydist
Hampton, Virginia 23361

39. High Temperature Instruments Corp.
225 W. Lehigh Ave.
Philadelphia, Pennsylvania 19133

40. Humphrey Inc.
2805 Canon Street
San Diego, California 92106

41. Hy-Cal Engineering
12105 Los Nietos Road
Santa Fe Springs, California 90670

42. Instron Corporation
2500 Washington Street
Canton, Massachusetts 02021

43. Instrumentation and Control Systems, Inc.
129 Laura Drive
Addison, Illinois 60101

44. Kahl Scientific Instrument Corporation
P.O. Box 1166
El Cajon, California 92022

45. Kaman Nuclear
A Division of Kaman Aircraft Corp.
1700 Garden of The Gods Road
Colorado Springs, Colorado 80907

46. Keystone Carbon Company
Thermistor Division
St. Marys, Pennsylvania

47. Kistler Instrument Corporation
8989 Sheridan Drive
Clarence, New York 14031

48. Kulite Semiconductor Products, Inc.
1030 Hoyt Avenue
Ridgefield, New Jersey

49. Larson Aero Development
P.O. Box 135
Concord, California

50. Lebow Associates, Inc.
21820 Wyoming Avenue
Oak Park, Michigan 48237

51. Lion Research Corporation
60 Bridge St.
Newton, Massachusetts 02195

Table XXIX. List of Instrumentation Manufacturers (Continued)

52. Lockheed Electronics Company
Houston Aerospace Systems Div.
Electro-Mechanical Lab.
900 Gemini Avenue
Houston, Texas 77058

53. Marin Controls Company
517 Marine View Avenue
Belmont, California 94002

54. Marlin Manufacturing Corporation
Research Instruments Inc. Division
12404 Triskett Road
Cleveland, Ohio 44111

55. Martin-Decker Corporation
1928 South Grand Ave.,
Santa Ana, California 92705

56. MB Electronics
A Textron Company
P.O. Box 1825
New Haven, Connecticut 06508

57. Metrix Instrument Co.
P.O. Box 36501
Houston, Texas 77036

58. Microdot Inc.
220 Pasadena Avenue
South Pasadena, California 91030

59. Minco Products, Inc.
7300 Commerce Lane
Minneapolis, Minnesota 55432

60. Nanmac Corporation
9 - 11 Mayhew St.
Framingham Centre, Massachusetts
01701

61. Pennsylvania Electronics Technology, Inc.
1397 Frey Road
Pittsburgh, Pennsylvania 15235

62. Pyro Electric, Inc.
Walkerton, Indiana 46574

63. Pyrometer Company of America, Inc.
600 East Lincoln Highway
Penndel, Pennsylvania

64. Radiation Research Corp.
26 Thayer Road
Waltham, Massachusetts 02154

65. RdF Corporation
23 Elm Avenue
Hudson, New Hampshire 03051

66. Relco Products, Inc.
5594 East Jefferson Avenue
Denver, Colorado 80237

67. Revere Electronic Division
845 North Colony Road
Wallingford, Connecticut 06492

68. Robinson-Halpern
5 Union Hill Road
West Conshohocken, Pennsylvania
19428

69. Rosemount Engineering Company
4900 West 78th Street
Minneapolis, Minnesota 55435

70. Schaevitz Engineering
U.S. Route 130 & Schaevitz Boulevard
Pennsauken, New Jersey

71. Science Associates Inc.
230 Nassau St.
P.O. Box 230
Princeton, New Jersey 08540

72. Sensor Technology and Instrument Division
Scientific Advances, Inc.
1400 Holly Avenue
Columbus, Ohio 43212

73. Servonic Instruments, Inc.
1644 Whittier Avenue
Costa Mesa, California 92627

74. Setra Inc.
12 Huron Drive
Natick, Massachusetts 01760

75. Shure Bros. Inc.
222 Hartrey Ave.
Evanston, Illinois 60204

76. Solid State Instruments, Inc.
2082 Lincoln Avenue
Altadena, California 91001

Table XXIX. List of Instrumentation Manufacturers (Continued)

77. H.E. Sostman & Co.
347 East Lincoln Ave.
Box 60
Cranford, New Jersey 07016

78. Sparton Southwest, Inc.
Subsidiary of Sparton Corporation
9621 Coors Road, N.W.
P.O. Box 1784
Albuquerque, New Mexico 87103

79. Standard Controls
2401 South Bayview
Seattle, Washington 98144

80. Statham Instruments Inc.
Aerospace Division
12401 West Olympic Blvd.
Los Angeles, California 90064

81. Streeter Amet
Grayslake, Illinois 60030

82. Systron-Donner Corporation
888 Galindo Street
Concord, California 94520

83. Teledyne Systems
Control Systems Division
200 N. Aviation Blvd.
El Segundo, California 90245

84. Tensitron, Inc.
Harvard Depot Road
Harvard, Massachusetts 01451

85. Thermal Systems Inc.
13920 S. Broadway
Los Angeles, California 90061

86. Thermo Electric
Saddle Brook, New Jersey 07662

87. Thermo-Systems Inc.
2500 Cleveland Avenue North
St. Paul, Minnesota 55113

88. Transducers, Inc.
11971 E. Rivera Road
Santa Fe Springs, California 90670

89. Trans-Sonics, Inc.
P.O. Box 326
Lexington, Massachusetts 02173

90. Tylan Corp.
4203 Spencer St.
Torrance, California 90503

91. Unholtz-Dickie Corporation
2994 Whitney Avenue
Hamden, Connecticut 06518

92. The United States Time Corporation
Eastern Sales: 375 Park Avenue
New York, New York 10022
Western Sales: 346 Tejon Place
Palos Verdes, California 90274

93. Versi Therm, Inc.
51 Toledo Street
Farmingdale, New York 11735

94. The Waters Corporation
P.O. Box 529
Rochester, Minnesota 55901

95. West Coast Research Corp.
2100-02 South Sepulveda Blvd.
Los Angeles, California 90025

96. Westberg Manufacturing Company
3400 Westach Way
Sonoma, California 95476

97. Whittaker Corporation
Instrument Systems Division
12838 Saticoy Ave.
N. Hollywood, California 91605

98. Winsco Data Sensors
1533 26th Street
Santa Monica, California 90404

99. Yellow Springs Instrument Co., Inc.
Yellow Springs, Ohio 45387

APPENDIX I

AEROSTATICS

1. INTRODUCTION

A tethered balloon is first of all an aerostat. Almost without exception the size of a balloon is determined by the number of cubic feet of lifting gas required to lift the balloon, payload, tether line and "free lift" to a given altitude in an assumed calm, or zero wind condition. Thus, aerostatics is the first basic science used in the analysis of balloon performance.

The simple perfect gas law is:

Pressure x Volume = gas constant x temperature

2. STATIC LIFT

Archimedes made the observation that a body immersed in a fluid is acted upon by a buoyant force equal to the weight of the fluid displaced. The force acts vertically upward. All problems in aerostatics reduce to this principle.

The lighter-than-air vehicle derives lift primarily through the principle of buoyancy; it can stay aloft although motionless with respect to its surrounding air. This lift is termed "static". An airplane must have motion relative to the air; a helicopter, although stationary, nevertheless depends on the motion of the rotor blades. Lift generated by motion is "dynamic". Many aerostats are capable of generating appreciable amounts of dynamic lift in addition to the static lift. Aerodynamic coefficient curves are presented at the end of this appendix.

3. SPECIFIC LIFT

Counteracting the buoyant force is the total weight of the body which, in the case of an aerostat, includes the weight of the gas with which it is inflated. Tethered balloons have the tensile force (and weight) of the mooring line, also. If a small balloon of one cubic foot volume is assumed, the buoyant force equals the weight of gas plus balloon weight, and the equation may be written:

$$w_a = w_g + w_T \qquad (4)$$

where,

w_a = weight of the one cubic foot of displaced air

w_g = weight of the one cubic foot of gas

and w_T = total weight of the balloon including any bit of weight that may need to be attached to the balloon to keep it floating, without rising or descending; i.e., to keep it "in equilibrium".

If w_g is transposed, the equation becomes

$$w_a - w_g = w_T \tag{5}$$

and (w_a - w_g) is variously called the lift coefficient, or specific or unit lift of the gas. For "standard day" conditions of 59°F, and 29.92 in. Hg, w_a = 0.0765 lb/cu ft and for pure helium w_g = 0.0106 lb/cu ft. Hence, the specific lift becomes 0.0659 lb/cu ft or roughly one ounce/cubic foot.

In actual practice the gas is never 100 per cent pure and a "standard day" is an exception. Humidity has a minor effect. Helium may be 99 per cent pure after the initial balloon or airship inflation and will drop slowly thereafter since air passes from the outside to inside through the envelope material at the same time that the lifting gas passes in the opposite direction. The rate of purity decay depends upon the envelope material, construction, and age. A "purity meter" is used to determine the gas condition.

In service the drop in purity depends upon facilities and/or available helium supply. In peacetime operations of Navy airships the facilities were generally excellent. A supply of fresh or purified gas was available at the main bases and "purging" was rather frequent. This consisted of adding high purity helium at the top of the envelope and simultaneously withdrawing impure helium from the bottom. The withdrawn gas was processed through a purifier and stored. As a result the helium in Navy airships was kept at an average purity of at least 95 to 96 per cent and, since the impurity was mostly air, a specific lift value of 0.063 lb/cu ft for a standard day was selected as a basis for performance estimates in recent years.

Since the unit weight of the air and gas, w_a and w_g, are similarly affected by temperature and pressure, it follows that their difference,

$w_a - w_g = c_\ell$, is similarly affected. Or the equation may be expressed:

$$c_{\ell_2} = c_{\ell_1}\left(\frac{T_1}{T_2}\right) \times \left(\frac{p_2}{p_1}\right) \tag{6}$$

where the temperatures and pressures are absolute values.

c_{ℓ_2} = unit lift at pressure p_2, and temperature T_2

c_{ℓ_1} = unit lift at pressure p_1, and temperature T_1

In the preceding paragraph the temperatures and pressures of the air and gas were assumed equal. The temperatures are frequently dissimilar and it is then necessary to apply the appropriate values to w_a and w_g, individually and before subtraction, to obtain c_ℓ. Any temperature differential between the air and gas is commonly called superheat - positive when the gas is warmer, and negative when colder. As a rule of thumb in practical operations, five degrees of superheat will change the gas lift one per cent.

$$\frac{\Delta T}{T} = \frac{5^\circ R}{519^\circ R} \approx 0.01$$

Any lighter-than-air gas in a container but exposed to atmospheric pressure at the bottom will have a pressure gradient increasing from the bottom to the top - the opposite of water in a pail. But the average pressure is only a few inches of water, compared to the atmospheric pressure of 34 feet of water, and is ordinarily neglected in lift estimates.

4. HUMIDITY

Humidity has the primary effect of decreasing the unit weight of the air, w_a, since the molecular weight of water vapor is less than that of air. Of course, the less the weight of the displaced air, the less the buoyancy. From the law of partial pressures the effect of humidity is applied as a subtraction of the vapor pressure from the barometric pressure and, therefore, the correction requires measurements of relative humidity and temperature. The corrections for saturated vapor, (100 per cent humidity), are shown in the following table and for any other humidity are proportionally less.

TABLE XXX
WATER VAPOR PRESSURE AS A FUNCTION OF TEMPERATURE

AIR TEMPERATURE °F	VAPOR PRESSURE, 100% R.H. p_v - IN. HG
0	0.0375
10	.0628
20	.1027
32	.1806
40	.2478
50	.3624
60	.5214
70	.7386
80	1.0314
90	1.421

AIR TEMPERATURE ^{o}F	VAPOR PRESSURE, 100% R.H. p_v - IN. HG
100	1.931
110	2 594
120	3.444

A slight discrepancy is now introduced. It has been stated that the impurity mixed in the gas is always assumed to be air which, in nature, is a mixture of gases including water vapor (reference Section IV). It has been observed that the amount of water vapor within an aerostat varies, after some lag, with the change of humidity in the ambient air. But it is not convenient to measure the amount in the helium and so it is assumed that the same relative humidity correction for the air weight is applicable to the helium weight. Therefore, whenever the humidity is to be included in the estimate for specific (unit) lift, it appears as a correction to both the air and helium and in the simple form of $(p - \emptyset\, p_v)$.

where p = atmospheric pressure, in. Hg
$\emptyset$ = relative humidity
p_v = vapor pressure at 100% humidity, in. Hg

Many estimates omit the humidity factor entirely since other inaccuracies, or unknowns, may far over-shadow the humidity effect.

5. SIMPLIFIED LIFT EQUATION

Taking the unit weights of air and helium for standard conditions, applying the temperature, pressure, and humidity corrections as discussed, and including a factor for purity, the specific lift expression becomes:

$$c_\ell = \theta \left[w_{a_o} \left(\frac{T_{a_o}}{T_a} \times \frac{p - \emptyset\, p_v}{p_o} \right) - w_{g_o} \left(\frac{T_{g_o}}{T_g} \times \frac{p - \emptyset\, p_v}{p_o} \right) \right] \quad (7)$$

where θ = purity

w_{a_o} = wt/cu ft air at 29.92 in and 59°F = .0765 lb/cu ft

w_{g_o} = wt/cu ft He at 29.92 in. and 59°F = .0106 lb/cu ft

T_{a_o} = absolute temperature of air, std = 460 + 59 = 519°R

T_a = absolute temperature of air, given = 460 + t_a

p = atmospheric pressure, in. Hg

$\emptyset$ = relative humidity

p_v = water vapor pressure at saturation, in. Hg

t_a = ambient temperature, degrees F

p_o = standard atmospheric pressure = 29.92 in. Hg

T_{g_o} = absolute temperature of He, standard = T_{a_o} = 519°R

T_g = absolute temperature of He, given = 460 + t_g

If T_a and T_g are equal, (i.e., no superheat), the equation reduces to:

$$c_\ell = 1.142 \frac{\theta}{T} (p - \phi\, p_v)$$

This result would be sufficiently accurate for practically all engineering calculations. Even with the humidity effect ($\phi\, p_v$) eliminated the value suffices for most proposal estimates. This further simplified form

$$c_\ell = 1.142 \frac{\theta\, p}{T} \tag{8}$$

has often been presented in graphical form as shown in Figure 25 for helium.

6. ELABORATED LIFT EQUATION

A still different equation for the specific lift of helium exists. This equation has been used in the evaluation of careful weigh-offs of airships, fully inflated with helium, from which - with a supposedly accurate actual weight - the actual exact volume is to be calculated. Weight engineers have used the following equation in such instances:

$$c_\ell = \theta \left[\frac{1.3245\ (p - .38\ \phi\ p_v)}{459.7 + t_a} - \frac{.18324\ (p + p_g + 3.5\ \phi\ p_v)}{459.7 + t_g} \right] \tag{9}$$

wherein θ = purity

p = atmospheric pressure, in. Hg

ϕ = relative humidity

p_v = water vapor pressure, saturated, in. Hg

p_g = gas pressure, gauge, in. Hg

t_a = air temperature, °F

t_g = gas temperature, °F

7. TOTAL STATIC LIFT

So far only the lift of one cubic foot of gas has been discussed. The total static lift of a balloon of any volume is:

Lift = Volume of gas (V) x specific lift of gas (c_ℓ)

8. SUPERHEAT

The evaluation of superheat may be obtained by the inclusion of air and gas temperatures in the foregoing formulas. Even simpler, the rule of thumb is that each 5°F of superheat (±) changes the static lift 1% (±). This holds only as long as the balloon is partially inflated, and is much less once the balloon is full and the expansion causes the gas to be released through the overpressure valve. The difference is simply explained by the basic formula for lift; i.e., total weight of displaced air, W_a, minus total weight of gas, W_g. In the partially inflated balloon increase in gas temperature increases the gas volume, and so displaces a greater volume and weight of air. Since W_g remains constant, $W_a - W_g$ must increase. Numerically,

$$\Delta L_{partial} = W_{a_1}\left(\frac{T_{g_2}}{T_{g_1}} - 1\right) \qquad (10)$$

where: T_{g_2} = final temperature of gas

T_{g_1} = initial temperature of gas (also = T_{air} = constant)

W_{a_1} = initial weight of displaced air.

When the balloon is full and a rise in gas temperature causes gas to be valved, the opposite is true - the weight of displaced air remains constant while the weight of gas decreases by the amount valved. Constant pressure within the balloon being assumed,

$$\Delta L_{full} = W_{g_1}\left(\frac{T_{g_2}}{T_{g_1}} - 1\right) \qquad (11)$$

where W_{g_1} = initial total weight of gas in balloon.

(Note: In this case the weight of the helium-air mixture for W_{g_1} must be used. The presence of only 5% by weight of air in the mixture makes it 30% heavier than pure helium.)

Thus, if the gain in lift with superheat for a balloon partially and then fully inflated were plotted it would be similar to Figure 75. Actually the relative slopes of the lines represent the weight of the air and of the inflation gas.

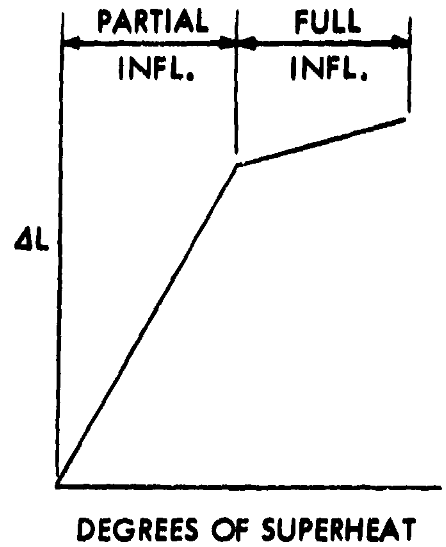


FIGURE 75. EFFECT OF SUPERHEAT ON STATIC LIFT

9. EFFECT OF ALTITUDE

The effect of altitude is nothing more than the combined effects of pressure and temperature which have already been treated. It is seldom possible to know in advance the exact values of these at any altitude and time; and the relationships of properties at one altitude to those at another are really not constant, particularly at lower altitudes. Nevertheless, "standard" values have been agreed upon for temperatures, pressures, and the corresponding air densities at altitudes up to several hundred thousand feet. These are tabulated and the ratio of the density, ρ, at any altitude to that at sea level, ρ_0, is usually given. This is a very convenient ratio for the engineer. This ratio applies to the density of a cubic foot of the lifting gas as well as the ambient air and, therefore, it applies to the difference of the densities, or to the unit lift. Some of the values are given in Table XXXI along with the unit lift, on the basis of 0.063 lb/cu ft at sea level, as previously explained (a purity of 95.5%).

The problem in reaching the high altitudes, such as 100,000 feet, is quite evident - the density and unit lift are only 1.4% of those at sea level.

TABLE XXXI
DENSITY RATIO AND UNIT LIFT AS A FUNCTION OF ALTITUDE
HELIUM - 95.5% PURITY

ALTITUDE ft	$\frac{\rho}{\rho_0}$	UNIT LIFT lb/cu ft
Sea Level	1.000	.063
1,000	.971	.0612
2,000	.943	.0594
5,000	.862	.0543
10,000	.738	.0465
20,000	.533	.0336
50,000	.153	.0096
100,000	.014	.0009

Since the densities of air and a gas vary with altitude according to the above table, the specific volumes must vary in the inverse manner. In other words, one cubic foot of gas at sea level will expand to

$$\frac{1}{0.862} = 1.16 \text{ cu ft at 5,000 feet, for instance.}$$

And, since it has been seen that the specific lift is reduced by the same factor of 0.862, the product of c x V is constant for all altitudes for a given aerostat if gas is neither added nor valved. Simpl ived:

$$c_{\ell_2} = \frac{\rho}{\rho_0} \times c_{\ell_1} \tag{12}$$

$$V_2 = \frac{\rho_0}{\rho} V_1 \tag{13}$$

Hence,
$$c_{\ell_2} \times V_2 = \frac{\rho}{\rho_0} c_{\ell_1} \times \frac{\rho_0}{\rho} V_1 = c_{\ell_1} \times V_1 \tag{14}$$

10. NONSTANDARD CONDITIONS

Problems often require consideration of conditions other than those described by the "standard atmosphere". Interest may be in a balloon launch altitude other than sea level and temperatures other than "standard". There are tables for a "hot day atmosphere", starting with a sea level temperature of 103°F, but these, too, are rather special (MIL-STD-210A).

Consider, for instance, that the problem requires the launch altitude to be at 5,000 feet above sea level and at a temperature of 95°F. The first requirement is a "standard day" table in which

temperatures are given for various altit les as well as densities. (Note: It frequently happens that estimators make the error of correcting for density ratios and temperatures. Of course, standard density ratios have the standard temperature effects already included. But to digress from the standard temperature, an estimator must know what that temperature is.) At 5,000 feet:

Standard temperature = 41°F

$$\frac{\rho}{\rho_0} = .86167$$

With the temperature of 95°F at 5,000 feet, the density ratio at standard day pressure becomes:

$$\frac{460 + 41}{460 + 95} \times .86167 = .7723$$

Therefore, with a helium lift coefficient of 0.063 lb/cu ft at sea level, at 5,000 feet and 95°F at that altitude, the lift coefficient would be:

$$.7723 \times .063 = .04865 \text{ lb/cu ft}$$

11. SUMMARY

Most aerostatic problems involve only three principal factors; namely, the density of the air surrounding the aerostat, the density of the gas within the aerostat, and the volume of this gas. Each of these is influenced by its respective temperature and pressure and, to a lesser extent, by humidity. Altitude as a numerical quantity never enters a calculation. The temperatures and pressures at an altitude may have been measured, assumed, or calculated. In the latter case Standard Atmosphere Tables are normally used in which the density ratios are equal to the ratios of the products of pressure and temperature ratios.

Finally, a few of the more common rules may be given.

(1) Lift of an aerostat varies with the volume if all other factors remain constant.

(2) Lift of a given volume of gas increases if barometric pressure increases and vice versa.

(3) Lift of a given volume of gas decreases if atmospheric temperature increases and vice versa.

(4) The higher the atmospheric humidity the less the lift.

(5) There is no change in equilibrium if the gas is free to change its volume and if the gas and air temperatures and pressures change by like amounts.

(6) An aerostat in equilibrium at one altitude will be in equilibrium at any other altitude providing no weight is lost or gained and the superheat value is not changed.

(7) Barometric pressure will decrease about one inch Hg for every 1,000 feet of ascent in the lower atmosphere.

(8) Atmospheric temperature will decrease approximately $1^{o}F$ for every 300 feet of ascent, or 3 $1/3^{o}$ for every 1,000 feet ascent.

(9) Gas volume and density are each changed, but oppositely, about 1 per cent for every $5^{o}F$ change in gas temperature, at constant pressure.

(10) Lift is changed about 1 per cent for each $5^{o}F$ difference in temperature between gas and air if the gas is free to expand but below the pressure height of the aerostat.

AERODYNAMICS

1. GENERAL

The preceding discussion has dealt with the aerostatics of lighter-than-air vehicles. Figure 76 presents the lift and drag coefficients for three tethered balloon shapes,

where:

$$\text{Dynamic Lift} = \frac{\rho v^2}{2} \left(C_L\right) \; V^{2/3}, \text{ and}$$

$$\text{Drag} = \frac{\rho v^2}{2} \left(C_D\right) \; V^{2/3}$$

The dynamic lift to drag ratio, L/D is equal to the ratio C_L/C_D for a given angle of attack; however, the total L/D ratio is given as:

$$\frac{\text{Net Buoyant Lift + Dynamic Lift}}{\text{Drag}} = \left(L/D\right)_{total}$$

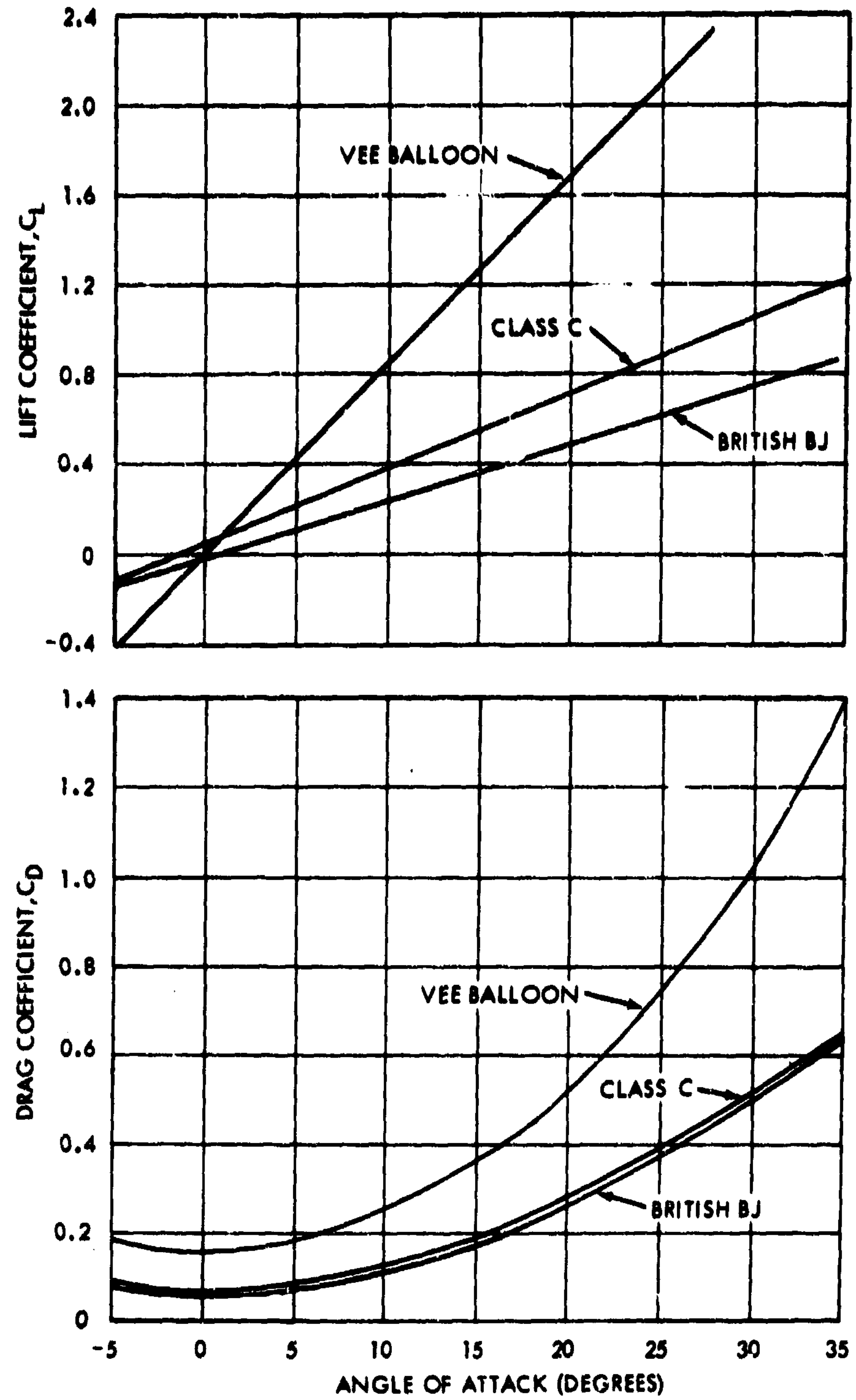


FIGURE 76
LIFT AND DRAG COEFFICIENTS VERSUS
ANGLE OF ATTACK FOR VARIOUS BALLOON CONFIGURATIONS

APPENDIX II

HELIUM FACT SHEETS

The following summary is to familiarize the reader with basic data regarding helium. It covers, in capsule form, helium's properties, history, distribution, uses, consumption, production, transportation and conservation.

This appendix is excerpted from information prepared by the Helium Centennial Committee from Government and Industry.

1. SUMMARY

Helium is the second lightest of the elements. It is colorless, odorless, tasteless, non-toxic material occurring in a gaseous state at all but extreme temperatures and pressures.

Helium is inert, that is, it is completely lacking in chemical activity. It will not burn nor explode.

Helium has the lowest liquefaction temperature (boiling point) of any known substance - approximately -452°F.

Helium is found in trace amounts in air and in most natural gases. In most instances the helium content is less than a few tenths of one per cent. In some areas, large volumes of natural gas contain more than 0.4 per cent, but generally less than 1 per cent. In a few instances, the helium content exceeds 2 per cent. The highest content observed is about 9 per cent.

Helium is extracted from natural gas by a cryogenic process, whereby the entire gas stream is cooled until most of it liquefies. The helium, still gaseous, is separated, and the liquid natural gas is then regasified for transmission to market.

Annual present helium usage in this country is nearly one billion standard cubic feet.

Except for a small plant in Canada, the United States is the only nation in the free world that extracts helium in commercial quantities.

2. HISTORY

J. Norman Lockyer, an English astrophysicist, is credited with the discovery of helium in 1868. He discovered new spectral lines in the chromosphere of the sun.

Onnes, in 1911, discovered superconductivity. Mercury at the temperature of liquid helium had no electrical resistance.

Helium for laboratory use in the United States before World War I was extracted from natural gas at a cost equivalent to $2,000 per cubic foot.

Production of the first helium gas in North America took place at a small plant near Hamilton, Ontario, in 1918. Under the direction of Professor John C. McLennan, Canadian physicist, of the University of Toronto, its purpose was to produce helium for observation balloons.

In 1918, three helium extraction plants were constructed in the United States under the technical direction of the Bureau of Mines - - two at Fort Worth and one at Petrolia, Texas. These plants extracted 200,000 cubic feet of helium - - slated for observation balloons in France. At the war's end, the plants were closed, and a larger extraction plant was constructed north of Fort Worth in 1921 under sponsorship of the U. S. Navy. Linde Air Products Company was the contractor for design, installation, and operation.

In December, 1921, the Navy's C-7 made the first helum-filled airship flight from U. S. Navy Air Station, Hampton, Virginia, to Bolling Field, District of Columbia.

In January, 1923, Professor (Sir) John C. McLennan, liquefied helium at the University of Toronto, the first time it was done on the American Continent.

On July 1, 1925, by an Act of Congress, the Government's helium program was placed under the Bureau of Mines.

Work by the Bureau of Mines, in 1925, showed the usefulness of helium as a breathing mixture with oxygen for deep sea divers. Helium-oxygen mixtures were first used by Navy divers in the salvage of the U. S. Submarine S-51 in July, 1926, from 132 feet of water. She had sunk September 25, 1925, with loss of all hands.

On June 25, 1926, Onnes first solidified helium in his laboratory. He reached a temperature of -457.5°F, but helium remained a liquid. Solidification was accomplished by applying pressure to the liquid helium.

The popularity of airships hit its peak in the 1930's, following the global passenger and freight-carrying feats of Germany's giant dirigible Hindenburg and by the nationwide flights of the U.S.S. Akron and Macon. The crash of three American dirigibles - - the Shenandoah in 1925, the Akron in 1933, and the Macon in 1935 - - set back the American dirigible program. These crashes, followed by the hydrogen-filled Hindenburg fire on May 6, 1937, put an end to the dirigible program in the United States.

Congress authorized sale of helium from Bureau plants to industry and for scientific and medical purposes in 1937, and also directed the Bureau to purchase the Helium Company's plants and properties.

In 1939, helium-oxygen mixtures were used by Navy divers to raise the U. S. Submarine Squalus from 240 feet of water where she sank off Portsmouth, New Hampshire. Of the 59 man crew, 33 were saved.

In 1942, the Amarillo Helium Plant was expanded to meet World War II needs for helium. Helium-filled blimps were built until 15 squadrons were in service for antisubmarine patrol and to escort ship convoys.

At the peak of operations, Navy airships patrolled an area of three million square miles off the Atlantic and Pacific coasts and in the Mediterranean Sea. Between 1942 and 1945, the airships escorted 89 thousand ships loaded with millions of troops and billions in military equipment and supplies without the loss of a single ship.

3. HELIUM'S USES

Estimated use of helium (gas and liquid) during 1966, in the United States, Canada, and countries of import, shown as percentage of total of 954 million cubic feet. Use is specifically for gas, unless LHe (liquid He^4) is noted.

	Per cent of total
(1) Launch vehicles and rockets (NASA and Air Force programs)	56
a. As an "ullage" medium, to displace fuels and oxidizers withdrawn from storage tanks or forced into the combustion chambers by helium pressure	
b. To purge fuel and oxidizer system in ground-support work for launch	
c. LHe - to pre-cool pumps on liquid-hydrogen-fueled space vehicles, to increase payload and accuracy	
(2) Metallurgical applications	14
a. In shielded-arc welding of magnesium, titanium, aluminum, copper, stainless steel, and other metals	

	Per cent of total
b. To provide an inert atmosphere for growing crystals of germanium and silicon in transistor and diode manufacture	
c. In furnaces for metal treating, and production of titanium and other metals	
d. To sparge dissolved gases from molten metals during purification	
(3) Nuclear and atomic energy applications (AEC program)	12
a. In high temperature, gas-cooled reactors as a heat-transfer, protective atmosphere, and coolant medium for nuclear reactors	
b. As artifically-accelerated projectiles for nuclear reactions	
c. LHe and LHe^3 - for bubble chambers	
(4) Miscellaneous	6
a. For detecting leaks in high-vacuum equipment and pressure containers	
b. In analytical chemistry, as a carrier gas in chromatography	
c. LHe - to provide an environment and necessary cooling for superconducting apparatus of all types - magnets, dynamos, transformers, gyroscopes, etc.	
d. In mixtures with other gases, especially neon, for lasers	
e. For gas-lubricated bearings in high-speed photography	
f. In luminous signs, of "neon" type, for advertising	
g. In optical instruments, to fill space between lenses	
h. In geological dating	

	Per cent of total
i. To provide an inert environment for preservation of historical documents	
(5) As a lifting gas	5
a. Weather balloons, in meteorological research	
b. Research balloons, for astronomical and astrophysical studies, such as high-altitude telescopic photographs of the sun, etc.	
c. A few commercially owned non-rigid airships	
d. "Kite-type" balloons to move timber in logging operations	
e. Toy balloons, including larger balloons for advertisting	
f. A few balloons for sport flying	
(6) Aerodynamic and space research	4
a. In wind tunnels and shock tubes to study design of airfoils, etc.	
b. LHe - for cooling masers in radio astronomy	
c. LHe - to produce high vacuum systems by "cryopumping" techniques for space simulation chambers	
(7) Low-temperature research	2
a. LHe and LHe^3 - in research aimed at reaching absolute zero	
b. LHe^3 - to provide refrigeration in the region 0.3 to 3^oK for any purpose where this temperature is needed (such as the storage of free radicals)	
c. LHe and LHe^3 - in theoretical studies of the liquid state, to explain superfluidity and to provide fundamental information on systems following Bose and Fermi statistics	

	Per cent of total
(8) Medical applications	1
a. In mixtures with oxygen, as a breathing atmosphere, in the treatment of asthma and respiratory diseases, and in the recovery room for "easy" breathing	
b. In mixtures with oxygen, as a breathing atmosphere, in space and oceanographic programs	
c. Same as b: for divers to prevent "nitrogen narcosis" (rapture of the deep)	
d. LHe - to quick-freeze living cells to promote their viability in cancer and other medical research	

4. HELIUM EXTRACTION, PURIFICATION

The extraction of the helium constituent of natural gas is done by making the mixture progressively colder until almost everything turns to liquid, excepting helium, which remains a gas.

This cooling is done by repeated cycles of compression, heat removal, and expansion of the natural gas, until at -275°F, everything has been condensed as a liquid except a gaseous helium-nitrogen mixture called crude helium.

The crude helium is then purified through activated charcoal cooled with liquid nitrogen.

The purified helium - - designated Grade A - - has a purity of 99.995 per cent, or maximum impurities of 50 parts per million.

5. TRANSPORTATION

Helium is shipped as a compressed gas in pressure vessels one of three ways:

(1) in specially constructed railway tank cars
(2) in specially constructed highway semitrailers (see Figure 77)
(3) in standard gas cylinders

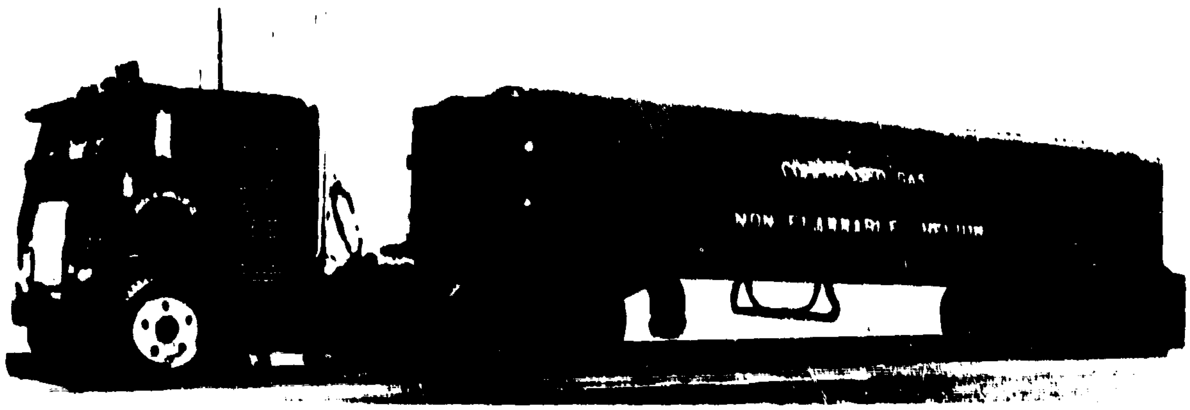


FIGURE 77. MODERN HELIUM TRACTOR TRAILER (128,230 CUBIC FEET)

The Federal Government owns the only railway tank cars; the active fleet totals 239. An average tank car has a capacity of about 275,000 cubic feet of helium when filled to a pressure to 4,000 psig. The tank cars are made of multiple forged-steel pressure vessels, and have a net weight of about 240,000 pounds. When filled to capacity, the helium cargo increases the car weight only by about 2,900 pounds.

Highway semitrailers have capacities ranging up to 150,000 cubic feet of helium, with filling pressures of about 2,600 psig. Construction is similar to railway tank cars. Some semitrailers are designed for "piggyback" service, i.e., for long-distance transport on railway flat cars.

A "standard" cylinder has a capacity of about 240 cubic feet of helium at a pressure of up to 2,400 psig.

Liquid helium is shipped in "dewars" of various sizes and in special, insulated over-the-road semitrailers. Dewars contain from 25 to 7,000 liters of liquid helium. They can be flown to destination, transported by truck or rail. The capacity of some semitrailers in liquid helium transportation service is 10,000 gallons each, which is equivalent to about one million cubic feet of gaseous helium.

6. RESERVES

Ninety-three per cent of the western world's known reserves of helium are located within a 300-mile radius of Amarillo, Texas. It is found as a constituent of natural gas. The Texas and

Oklahoma Panhandles, together with northeastern Arizona, northwestern New Mexico, and Kansas are the best known sources of supply. All present helium plants are located in these states. Helium is also present as a constituent of natural gas in Canada, and in a few other parts of the world, but these sources are minor in importance compared to the volume available in the United States.

Other natural gas fields containing helium in the United States are known to exist in Montana, Wyoming, Colorado, Arizona, New Mexico, Utah, and Michigan. American gas fields contain a known total reserve of about 200 billion cubic feet of helium in concentrations greater than .3 per cent.

The world capacity to convert gaseous helium to liquid helium is about 12.2 million liters per year, equivalent to 325 million cubic feet of 99.995 per cent gaseous helium.

In the United States, although one natural gas source containing 8 per cent helium has been discovered, the average percentage is much lower, generally ranging less than 1 per cent. In Canada, the richest helium bearing gases have been found in Saskatchewan, where the natural gas sources contain about 2 per cent helium.

Helium used in other areas of the free world is imported from the United States or Canada. Current exports from the United States are at the rate of about 12 million cubic feet a year. Major purchasers are Canada, the United Kingdom, France, Japan, and West Germany.

7. CONSUMPTION

From the time it was discovered in 1868, to the outbreak of World War I, helium was extracted in only a few scientific laboratories, and the world's total production did not exceed 100 cubic feet. The cost was $2,000 to $3,000 per cubic foot.

By contrast, the volume consumed in the United States in 1966, which does not include the volume extracted and stored in the Bureau of Mines conservation program, was 954 million cubic feet. The Bureau of Mines sale price to commercial customers was 3 1/2 cents per cubic foot. A clearer picture of helium's rate of growth can best be obtained from these Bureau of Mines helium consumption figures.

Year	Cubic Feet (000,000)	Year	Cubic Feet (000,000)
1950	81	1958	352
1951	109	1959	375
1952	145	1960	475
1953	158	1961	551
1954	190	1962	630
1955	236	1963	662
1956	267	1964	713
1957	310	1965	760
		1966	954

By 1970, consumption is expected to reach 1.2 billion cubic feet, a 60 per cent increase over 1965.

8. CONSERVATION

A helium conservation program was authorized by the Helium Act Amendments of 1960 (Public Law 86-777), and subsequent legislation established the annual funding level of the program at $47.5 million.

The concept of the program is simple. Helium is extracted from helium-bearing natural gas after the gas is produced but before it reaches its ultimate market. This helium is then gathered from various plants and stored underground in a partially depleted natural gas-bearing formation in the Cliffside gas field near Amarillo, Texas. When needed, the helium will be withdrawn, purified, and sold to federal agencies or commercial customers.

Concurrently with the construction of the five plants, the Bureau of Mines built a 425-mile pipeline system, tieing the plants - - as well as the Bureau-owned plants at Otis, Kansas; Keyes, Oklahoma; Exell, Texas; and Amarillo, Texas, to the Cliffside gas field. (See map, Figure 78)

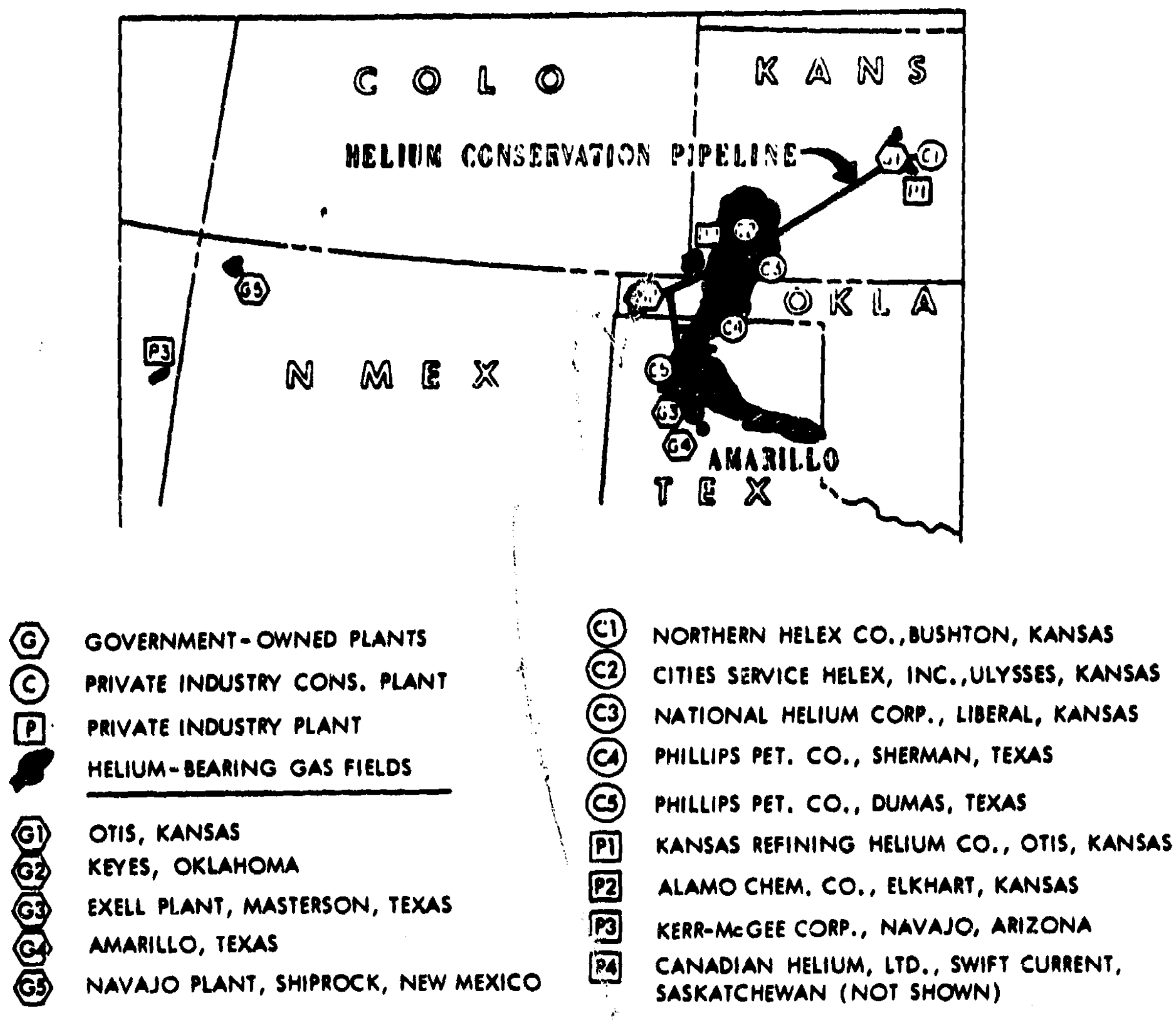


FIGURE 78. HELIUM CONSERVATION MAP

First delivery of conservation helium occurred in December, 1962. By mid-1967, nearly 15 billion cubic feet of helium had been purchased by the Bureau of Mines and stored in the Cliffside field.

The Bureau of Mines acquired the Cliffside field in 1929, as a source of helium-bearing gas to supply the Bureau's Amarillo Helium Plant. It still serves this function as well as being utilized as a storage reservoir for the conservation of helium.

TABLE XXXII
DATA ON HELIUM PLANTS

PLANT	OWNERSHIP	INITIAL OPERATION	APPROXIMATE AVG. HELIUM CONTENT OF GAS STREAM (MOL %)	APPROXIMATE ANNUAL CAP. (MILLION CU. FT.)	HELIUM CONTENT OF PRODUCT (MOL %)
High-purity helium plants:					
Amarillo, Texas	Bureau of Mines	Apr. 1929	1.8	60	99.995
Exell, Texas	- - - do - - -	Mar. 1943	.9	280	99.995
Navajo (Shiprock) New Mexico	- - - do - - -	Mar. 1944	5.7	80	99.995
Keyes, Oklahoma	- - - do - - -	Aug. 1959	2.0	300	99.995
Navajo, Arizona	Kerr-McGee Corp.	Dec. 1961	8.2	70	99.995 & Liquid
Swift Current, Saskatchewan, Canada	Canadian Helium Limited	Dec. 1963	1.9	36	99.995
Otis, Kansas	Kansas Refined Helium Company	Apr. 1966	2.0	180	99.995 & Liquid
Elkhart, Kansas	Alamo Chemical Co. & Gardner Cryogenics Corp.	Dec. 1966	0.6	140	99.995 & Liquid
Total -				1146	- - - - - - - - - - -
Conservation Plants:					
Otis, Kansas	Bureau of Mines	Oct. 1943	1.4	50	50.0
Buston, Kansas	Northern Helex, Inc.	Dec. 1962	.46	675	60.0
Hansford Ct., Tex.	Phillips Pet.Co.	- - do - -	.78	1/788	50.0
Dumas, Texas	- - do - - -	Apr. 1963	.65	- - -	50.0
Ulysses, Kansas	Cities Ser.	June 1963	.43	610	70.0
Liberal, Kansas	Natl. Hel.Corp.	July 1963	.40	1053	60.0
Total -				3176	
Grand Total - - - - - - - - - - - - - - - - - -				4322	

1/ Combined Capacity 2-Plants

Prior to the conservation program, estimates indicate that more than 6 billion cubic feet of helium was being wasted each year when helium-bearing natural gas was produced and consumed.

Helium use is expected to increase to about 2 billion cubic feet a year by 1985. The present program is expected to meet these needs beyond the year 2000.

A unique feature of the federal helium program is its financing. The program is financed by a special fund, into which all revenue from the sale of helium and related activities by the Bureau of Mines is deposited. The fund is supplemented as necessary by borrowings from the United States Treasury. The authorizing legislation provides that all monies borrowed from the Treasury be repaid, with interest, in not more than 35 years. The Bureau of Mines sales price of helium, applicable to both federal agencies and private companies, is designed to generate sufficient revenue over the time period to repay the Treasury loans.

TABLE XXXIII
CONVERSION DATA FOR HELIUM

	POUNDS	TONS	SCF GAS	GALLONS LIQUID	CU. FT. LIQUID	LITERS LIQUID
1 Pound	1.0	0.0005	96.71	0.9593	0.1282	3.631
1 Ton	2000.0	1.0	193,424.0	1,919.0	256.5	7,262.0
1 SCF Gas	0.01034	0.00000517	1.0	0.009919	0.001326	0.03755
1 Gallon Liquid	1.042	0.0005212	100.8	1.0	0.13368	3.78533
1 Cu. Ft. Liquid	7.798	0.003899	754.2	7.48052	1.0	28.3162
1 Liter Liquid	0.2754	0.0001377	26.63	0.264178	0.0353154	1.0

SCF (Standard Cubic Feet) of Helium Gas Measured at 70°F and 14.7 psia

Liquid quantities are measured at the boiling point of helium - 452.1°F and 14.7 psia

APPENDIX III

TETHERED BALLOON SITES

1. GENERAL

The selection of an area from which to fly a tethered balloon will depend on the function or mission of the balloon system. This appendix will point out some of the fundamental considerations. The appendix also includes a listing of a number of areas which are restricted to air traffic and could with proper authorization and scheduling permit a tethered balloon flight within their boundaries. Permission to list these areas was granted at the time of publication and may change in the future. In all cases the user must notify the responsible person or office well in advance of the proposed balloon flight to obtain proper authorization and scheduling.

2. CLIMATOLOGY

Before any balloon flight area is selected, a knowledge of the operating environment is essential. The minimum required data includes wind conditions and the temperatures over an extended period of time. The data should cover not only ground conditions but also conditions for all altitudes through which the tethered balloon will be operated. Most of the climate information can be taken from Weather Bureau reports. In some areas special problems may exist, necessitating a specific study of climate information.

3. REQUIRED PHYSICAL CONDITION OF LAUNCH SITE

The minimum requirements for a launch site are a bedding down area, winch area and an area for either a permanent or mobile supply of lifting gas. The area should, when possible, allow the balloon to head into the prevailing wind. When practical, the bedding down area can be behind a large hill or buildings at a distance to afford some weather protection.

4. PERTINENT FAA REGULATIONS

Launch sites for tethered balloons must meet with the approval of the Federal Aviation Agency (FAA). The FAA is responsible for keeping to a minimum the number of hazards to which the aircraft using this airspace are subjected.

In order to obtain FAA approval to conduct a test, three different approaches are possible: Meet all existing FAA regulations; meet as many existing regulations as feasible and obtain waivers from FAA on those which cannot be met; choose for the launch site an area over which the airspace is restricted through the highest required altitude.

In every case approval must be obtained from the resident surface authority.

Federal Aviation Regulations pertaining to tethered balloons can be found in "Federal Aviation Regulations", Part 101, Subpart B, Moored Balloons and Kites. The regulations govern the operation in the United States of any balloon that is moored to the surface of the earth or an object thereon and has a diameter of more than 6 feet or a gas capacity of more than 115 cubic feet. If the balloon is to be operated within a restricted area, only requirements of section 101.19 (Rapid Deflation Device), with any limitations imposed by the using or controlling agency, apply.

The operating limitations of a moored balloon are as follows:

(1) The balloon must be not less than 500 feet from the base of any cloud.

(2) The balloon must be not more than 500 feet above the surface of the earth.

(3) The balloon must not be in an area where the ground visibility is less than three miles.

(4) The balloon must not be within five miles of the boundary of any airport.

These limitations do not apply if the operation of a balloon is below and within 250 feet of any structure; in that case, operation must not obscure any lighting on the structure.

At least 24 hours before beginning an operation, the following information must be provided to the FAA Air Traffic Control (ATC) facility nearest to the place of intended operation before any moored balloon that is more than 6 feet in diameter or 115 cubic feet in volume is flown more than 150 feet above the surface of the earth:

(1) The names and addresses of the owners and operators.

(2) The size of the balloon.

(3) The location of the operation.

(4) The height above the surface of the earth at which the balloon is to be operated.

(5) The date, time, and duration of the operation.

All tethered balloons that are flown in unrestricted airspace must be marked and lighted according to Federal Aviation Regulation 101.17, "Lighting and Marking Requirements", and the Federal Aviation Agency publication "Obstruction Marking and Lighting".

The requirement states that no person may operate a moored balloon or kite by day unless its mooring lines have colored pennants or streamers attached at not more than 50-foot intervals, beginning at 150 feet above the surface of the earth, and visible for at least one mile. Flags used for daytime marking should be not less than 2 feet on a side and aviation orange in color. When lights are used for night obstruction marking, the flashing frequency should be not more than 40 flashes per minute, nor less than 12 flashes per minute, with a period of darkness equal to approximately one-half the luminous period. The intensity of fixed obstruction lights should be not less than 10 candles of aviation red light.

Some of these requirements may vary for special conditions. Specification A-11 in the FAA publication "Obstruction Marking and Lighting" contains the following statement:

> "Towers and similar obstructions which are more than 1500 feet in overall height above ground, or water if so situated, will be given special aeronautical study to determine the proper manner in which to obstruction light them to provide adequate protection for air commerce."

In this case, contact your local FAA representative for proper tethered balloon marking requirements. All tethered balloons must incorporate a device that will automatically and rapidly deflate the balloon if it escapes from its moorings. If the device does not function properly, the operator shall immediately notify the nearest ATC facility of the location and time of the escape and the estimated flight path of the balloon.

When a tethered balloon flight is scheduled, application for certificate of waiver or authorization (FAA Form 400) should be made in triplicate and sent to the ATC facility nearest to the location of the tethered balloon flight.

When a tethered balloon flight is scheduled in a restricted airspace, compliance with section 101.19 (Rapid Deflation Device) and permission and complianc with the regulations set up by the using agency of that restricted airspace are required.

5. AVAILABLE SITES

The following pages list the restricted areas which, with proper authorizations and scheduling, will permit tethered balloon flights. Each area is described briefly, along with the address of the person or office to be contacted for permission or information as to use of the area. Figure 79 shows the approximate geographical location of each site which responded affirmatively as to their availability for tethered balloon flights.

FIGURE 79. LOCATIONS OF POSSIBLE TETHERED BALLOON LAUNCH SITES

RESTRICTED AREA R-2303A - Fort Huachuca, Arizona

LOCATION: Libby Army Airfield, Fort Huachuca, Arizona 85613

OPERATOR: U.S. Army, Fort Huachuca

ADDRESS: Russell N. Dragoo
Installation Airspace Office, SCCH-AF
Libby Army Airfield
Fort Huachuca, Arizona 85613
Telephone: (602) 538-4158, 538-3031

AVAILABILITY REQUIREMENTS:

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Must be arranged
d. Time limitations - None

ALTITUDE LIMITATION:

a. Launch Altitude - 4,500 ft. MSL
b. Flight Level - Surface to 35,000 ft. MSL
c. Restrictions - Continuous - IFR/VFR

WEATHER CONDITIONS:

a. Temperature (approx.)

winter low	10°F	Avg	45°F
summer high	105°F	Avg	73°F

b. Wind (surface)

high	50 knots	Avg	5-10 knots

c. General
Of the 13 inches of annual rainfall, the majority falls during the months of June thru September. Violent thunder storms during this period generate heavy rains with high winds. The remainder of the year is generally fair, with light winds and low humidity.

REMARKS:
Instrumentation Available -

Tracking, surveillance and height finding radar, telemetry, cinetheodolities, antenna pattern measurement, spatrol resolution facility, automatic data processing data reduction, radar spoke (for measuring range accuracy, range and azimuth resolution between 1 and 512 meters, of ground and airborne radars in fixed mode of operation).

Moving target indicator (MTI) timing central, real time display of telemetry information and air to ground UHF communication.

Photographic equipment is available from speedgraphics to cinetheodolites and can be arranged.

Office space is available but is limited to one or two desks. Hangar space is at a premium. No manpower or engineers are available. Meteorological information is available from weather forecasters at Libby Army Airfield.

NCAR Balloon Launch Site, Page, Arizona

LOCATION: Glen Canyon Dam, Page, Arizona

OPERATOR: NCAR

ADDRESS: Alvin F. Morris, Manager
Scientific Balloon Facility
National Center For Atmospheric Research
Box 1470
Boulder, Colorado

AVAILABILITY REQUIREMENTS:

Page has the same availability requirements as Palestine. However, Page is primarily used during the winter months due to the direction of the high altitude prevailing winds.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 4,250 ft. MSL
b. Flight Level - see remarks
c. Restrictions - see remarks

WEATHER CONDITIONS:

Not available.

REMARKS:

The Page, Arizona site is not in restricted airspace, therefore, all FAA regulations must be adhered to if a waiver cannot be obtained. Page is primarily a free balloon launch site and is suited for such an operation. Page has two great advantages:

(1) The natural, 700 ft. deep shelter provided by the canyon below the Glen Canyon Dam is eminently suitable for static launch of very large balloons and delicate payloads which cannot tolerate the accelerations of a dynamic launch.

(2) The location is well away from established airlanes.

The permanent winter launch facilities at the airport would consist of an 80 by 40 ft. prefabricated metal building to contain offices, workshop and staging areas, and a graded and stabilized launching area measuring 750 ft. square and located at the northeast corner of

the airport. The projected development of the canyon site would comprise a 150 x 700 ft. paved launch area, a staging building, and an elevator.

RESTRICTED AREA R-2306B - Yuma West Proving Ground, Arizona

LOCATION: Yuma Proving Ground, Yuma, Arizona 85364

OPERATOR: U.S. Army Test and Evaluation Command

ADDRESS: Commanding General
U.S. Army Test and Evaluation Command
Attn: AMSTE-PO-O
Aberdeen Proving Ground, Maryland 21005
Telephone: Ext. 4394

AVAILABILITY REQUIREMENTS:

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Must be arranged
d. Time limitations - 0001 to 2400 hours, MST daily, Monday thru Sunday

ALTITUDE LIMITATIONS:

a. Launch Altitude - 1200 ft. MSL (approx.) mountain peaks to 2800 ft. MSL
b. Flight Altitude - Surface to 80,000 ft. MSL
c. Restrictions - 0001 to 2400 hours, MST daily, Monday thru Sunday

WEATHER CONDITIONS:

a. Temperature (approx.)

winter low	30°F	Avg	56°F
summer high	118°F	Avg	93°F

b. Winds (surface)

High - 60 knots		Avg	4 knots

REMARKS:

Instrumentation available - Cinetheodolite, Telemetry Radar, Doppler, and data reduction.

Photographic equipment available - high speed, air-to-air, ground-to-air, and still.

Hangar and office space is available but is limited at times and could be coordinated. All services including manpower, meteorologists and engineers are in critical shortage and must be scheduled

if needed. Additional information pertaining to the area may be obtained by calling the Airspace and Range Office, Ext. 2586, Yuma Proving Ground, Arizona.

RESTRICTED AREA R-2510 - El Centro, California

OPERATOR: United States Air Force, Navy, and Army

ADDRESS: Air Force Flight Test Center (FTOP)
Edwards Air Force Base
California, 93523
(also send information copy to -)
USAF 6511th Test Group (FTNF)
Naval Air Facility
El Centro, California 92243

AVAILABILITY REQUIREMENTS:

a. Who may use it - All Military services, National Aeronautics and Space Administration and industrial organizations.

b. Priorities - DOD
c. Scheduling - Must be arranged
d. Time Limitation - Sunrise to sunset, Monday through Friday, from 20,000 ft. MSL to 500,000 ft. MSL.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 42 ft. MSL
b. Flight Level - surface to 500,000 ft. MSL
c. Restrictions - Continuous, surface to 20,000 ft. MSL; sunrise to sunset, Monday through Friday, 20,000 ft. to 500,000 ft. MSL

WEATHER CONDITIONS:

a. Temperature (approx.)
winter low 40°F Avg 65°F
summer high 120°F Avg 90°F

b. Winds (surface)
high 2-knots Avg 0-5 knots

REMARKS:

El Centro is basically a test and recovery test center. It is equipped with all type of instrumentation. The range has cinetheodolites (to 30 frames per second) telescopic cameras, telemetry receiving station (fixed and mobile), radio communications (UHF, VHF, FM), and tracking radar. It has test vehicles instrumented with FM/FM telemetry and

mechanical tensiometers. El Centro has several types of photography equipment on hand; ground-to-air, air-to-air, bomb bay-to-air, and boat-to-air. The data processing capabilities are as follows: Scientific Data System 930 digital compueter, Bensen Lehner Bosear N. cinetheodolite film reader and associated card punch equipment. Control Data Corporation G-15 digital computing system, and Electronic Associates Plotter No. 3300. El Centro is located on a 9,500 foot, hard-surface, lighted runway at a -42 feet elevation. If further information about the facilities is required contact:

Commander
6511 Test Group (FTNP)
El Centro, California 92243

RESTRICTED AREA R-2801 - Bethany Beach, Delaware

LOCATION: Bethany Beach, Delaware

ADDRESS: The Adjutant General
State of Delaware
10th and Du Pont Streets
Wilmington, Delaware 19899
Telephone: (302) 654-7761

AVAILABILITY REQUIREMENTS:

The area is used for artillery firing by the Delaware Army National Guard approximately forty days per year. Use of the area must be arranged in advance.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 0 ft. MSL
b. Flight Level - surface to 23,5000 ft. MSL
c. Restrictions - June 1 through September 30

Monday through Friday, 8:00 A. M. to 6:00 P. M. local time. October 1 through May 31, Saturday and Sunday, 8:00 A. M. to 4:00 P. M., local time.

WEATHER CONDITIONS:

a. Temperature (approx.)

winter low	0^oF	Avg	30^oF
summer high	100^oF	Avg	80^oF

b. Wind (surface)

high	50 knots	Avg	15 knots

c. General
The area is characterized by high humidity and frequent and sudden changes of weather.

REMARKS:

The area is primarily used for artillery firing and no other facilities are available.

RESTRICTED AREA R-2902A - Cape Kennedy, Florida

LOCATION: Patrick Air Force Base, Florida

OPERATOR: U. S. Air Force, Patrick Air Force Base

ADDRESS: Commander, Air Force Eastern Test Range
Range Control Section (ETOOT-1)
Patrick AFB, Florida
Telephone: (305) 853-5941

AVAILABILITY REQUIREMENTS:

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Must be arranged
d. Time limitations - None

ALTITUDE LIMITATION:

a. Launch Altitude - 9 ft. MSL
b. Flight Level - Unlimited
c. Restrictions - Continuous

WEATHER CONDITIONS:

a. Temperatures (approx.)

winter low	57°F	Avg	64°F
summer high	87°F	Avg	81°F

b. Wind (surface)

high	15 knots	Avg	10 knots

REMARKS:

Radar, telemetry, command, and a large variety of minor instrumentation is available. Photographic equipment, hangar and office space, and manpower, engineers, meterologists of all types and varieties are available. Tethered balloon experiments have been conducted on Cape Kennedy Air Force Base.

RESTRICTED AREA R-4201 - Camp Grayling, Michigan

LOCATION: Grayling Military Reservation, Grayling, Michigan

OPERATOR: State of Michigan

ADDRESS: Adjutant General, State of Michigan
Attention: LTC Howard G. Brunette
Airspace Utilization Offices
Abrams Airport P.O. Box 109
Grand Ledge, Michigan 48837
Telephone: (517) 627-6954

AVAILABILITY REQUIREMENTS:

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Must be arranged
d. Time Limitations - See remarks

ALTITUDE LIMITATIONS:

a. Launch Altitude - 1200 ft. MSL
b. Flight Level
    North Portion
        June through August to 29,000 feet
        September through May to 20,000 feet
    South Portion
        June through August to 9,000 feet
        September through May - not a restricted area
c. Restriction
    June through August - 24 hours
    September through May - Sunrise to sunset.

WEATHER CONDITIONS:

a. Temperatures (approx.)

winter low	-41°F	Avg	23°F
summer high	106°F	Avg	61°F

b. Wind (surface)

high	40 knots	Avg	15 knots

REMARKS:

There are no facilities available other than the restricted area. The area is used extensively during the months of June through August by National Guard units from Michigan, Indiana, and Ohio. During spring and fall of the year used on numerous weekends by Air National Guard for strafing runs and also used by Artillery and Mortar units of Army National Guard ground forces. Very little activity during winter months.

RESTRICTED AREA R-4401 - Camp Shelby, Mississippi

LOCATION: Camp Shelby, McLaurin, Mississippi

OPERATOR: Mississippi National Guard

ADDRESS: LTC Warwich B, Beane
Installation Airspace Officer
Camp Shelby, McLaurin, Mississippi 39401
Telephone: (601) 582-2364, (601) 582-2365

AVAILABILITY:

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Advance notification required
d. Time Limitations - None

ALTITUDE LIMITATIONS:

a. Launch Altitude - 250 ft. MSL
b. Flight Altitude -
   R-4401 Alpha - Surface to 4000 ft. MSL
   R-4401 Bravo - 4000 ft. to 18,000 ft. MSL
   R-4401 Charlie - 18,000 ft. to 29,000 ft. MSL
c. Restrictions
   Area activated by NOTAM to Houston. Must state type activity, times of use, altitudes, marking of tether, etc. All flights must stay within boundary of R-4401, unless approved by FAA.

WEATHER CONDITIONS:

a. Temperature (approx.)
   December, January and February:
      Normal daily temperature 60°F max., 39°F min.
      Average days 32°F or below - 27
      Days with precipitation - 32
      Clear or partly cloudy - 45
   June, July and August:
      Normal daily temperature 93°F max., 70°F min.
      Average days temperature 90°F or above - 73
      Days with precipitation - 27
      Clear or partly cloudy - 70
b. Wind - not given

REMARKS:

Instrumentation, photographic equipment, and services are not available. Office space in various buildings is complete with basic utilities, office furniture, telephones, etc., off and on post are available. Tethered balloon have been flown from Camp Shelby.

RESTRICTED AREA R-4809 - Tonopah Test Range, Nevada

LOCATION: Tonopah Test Range, Tonopah, Nevada

OPERATOR: Sandia Corporation for Atomic Energy Commission

ADDRESS: Sandia Corporation
Attention: Mr. S. A. Moore, Manager
Tonopah Test Range
Box 871
Tonopah, Nevada 89049
Telephone: (702) 986-0390

AVAILABILITY REQUIREMENTS:

When not required for AEC tests, the range is available on a reimbursable basis to other government agencies or contractors. In this role the range provides regular support for Air Force, Navy and Strategic Air Command (SAC) operational and test groups, and for NASA and some Defense contractors.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 5,300 ft. MSL
b. Flight Level - Unlimited
c. Restrictions - Continuous

WEATHER CONDITIONS:

a. Temperatures (approx.)

winter low	-10°F	Avg	35°F
summer high	100°F	Avg	70°F

b. Winds (surface)

high	30 knots	Avg	5 - 10 knots

c. General
The alluvial desert valley in which TTR is located is an area of low precipitation, averaging six inches yearly, with generally good visibility and minimum cloud coverage. The Sierra Mountain Range to the west blocks most of the Pacific-originated storms and the desert area to the east exhausts moisture from storm clouds moving from that area. When storms do reach the area from the west they generally deposit little moisture but cause a high cloud cover which is usually of short duration. The few storms which deposit moisture and remain in the area for some period of time usually move in from the southwest.

REMARKS:

TTR is a well-instrumented test facility. The range, not

including joint-use areas, is about 24 mile wide by 26 mile long with a total land area of 369,280 acres. The joint-use area extends in a northeasterly direction from the main range area and is approximately 25 miles wide and 75 miles long. Range tracking systems divide into two categories, optical and electronic. The bulk of the equipment for both categories is installed at permanent stations but some mobile equipment is available for movement to temporary positions. This mobile equipment is used to supplement regular range coverage and for data accumulation from isolated locations. All stations, including mobile, are supplied (by landline or radio link) with timing signals, range-to-target information, and communication and acquisition information.

RESTRICTED AREA R-5107 - Holloman AFB, New Mexico

LOCATION: AFMDC, Holloman AFB, New Mexico

OPERATOR: Detachment 1 AFCRL operates two tethered balloon sites near Holloman AFB. AFCRL facilities are available for use at either site. One site is on air base property, but use is limited by handling facilities and proximity of runways. The other site is on White Sands Missile Range and is approximately 95 highway miles north northwest of Holloman AFB.

ADDRESS: Det 1, AFCRL (CREH)
Holloman AFB, New Mexico 88330

AVAILABILITY: Both Sites

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - DOD and WSMR
d. Time Limitations - None

ALTITUDE LIMITATIONS: Holloman AFB

a. Launch Altitude - 4100 ft. MSL
b. Flight Altitude - 5600 ft. MSL (max.)
c. Restrictions - Daylight only

WSMR

a. Launch Altitude - 4727 ft. MSL
b. Flight Altitude - Unlimited
c. Restrictions - None

WEATHER CONDITIONS:

Holloman AFB and Granjean Tethered Balloon Sites

a. Temperature Range - The mean minimum and maximum temperatures for the coldest and warmest months are 28°F and 93°F for Holloman AFB and are 19°F and 92°F for Granjean.
b. Climatic Conditions
   1. Seasonal Limitations - The use of the Holloman AFB and Granjean launch sites is limited from mid-June to mid-September by frequent afternoon thunderstorms accompanied by gusty surface winds.
   2. Temperature - Both sites have a desert climate. The mean annual temperatures for Holloman AFB and Granjean are 61°F and 57°F, respectively.
   3. Moisture - Both areas are dry with an annual rainfall of 7 inches for Holloman and 10 inches

for Granjean. The average relative humidity for Holloman is 34 per cent.

4. Climatic Classification - The climate for both sites is an inland type with most of the precipitation occurring during the summer months.
5. Winds - Surface winds at Holloman AFB and Granjean are generally light from 2000 until about 0900 the year round. The afternoon surface winds are strong in the spring and gusty during the summer months in the vicinity of thunderstorm activity.

FACILITIES AND SERVICES:

Each investigator is expected to be completely self-contained. The staff and equipment is directed toward operational phases of balloon flight. The site is not equipped to accommodate the infinite variety of services each experiment may require. Similarly, the White Sands Missile Range is equipped to provide IRIG data acquisition services but cannot supply personnel or equipment for direct use by the investigator.

The following is a general list of what is available:

a. Office Space - Minimum office and assembly space are available at Holloman AFB.
b. Machine Shop - Service is limited to emergency repair of heavy equipment. Facilities for machine work to higher orders of tolerance is extremely limited.
c. Photo Equipment - For use by experimenter is not available. Documentary still, motion and processing service provided.
d. Environmental Equipment - Service provided. Several chambers are available. Largest size 8 feet wide by 8 feet high by 11 feet long. Altitude range is sea level to 220,000 feet. Temperature range is minus 100°F to plus 200°F. Humidity can be controlled.
e. Electronic Test Equipment - Not available.
f. Launch Equipment (Winches, Cables, Trucks, Storage) See Section V.
g. Tracking Aircraft - Provided by the Air Force, if required.
h. Standard Telemetry and Command Systems - UHF command receivers, telemetry transmitters and sensors are not available. Compatible IRIG command transmitter service and IRIG telemetry checkout and recording service are available.
i. Helium storage and transportation to sites is available.
j. Meteorological - WSMR has permanently installed rawinsonde facilities at Holloman AFB and Stallion

Site, approximately 12 miles from Granjean. In addition, four other fixed rawinsonde facilities and six automatic surface weather recording facilities are located on the range. AFCRL has complete meteorological data receiving equipment and forecast capability at Detachment 1. Arrangements can be made for real time environmental data and post flight data reduction.

SERVICES AVAILABLE:

a. Consulting - Consulting services are available prior to flying at Headquarters, AFCRL. Meteorologists, Instrumentation Engineers, and Balloon Design personnel are available for consultation. Contact Mr. Thomas Danaher, phone (617) 274-6100, extension 3005.
b. Technicians are available for balloon launching, tracking and recovery. No electronic technicians are available to the user.
c. Purchasing Service - Helium, balloons, and balloon associated equipment are available on a refundable basis. Normally all requirements for a given year are pooled and a single purchase initiated.

Miscellaneous - Cinetheodolites are available for position data, and first and second derivatives of position are available through WSMR data reduction facilities.

RESTRICTED AREA R-5311 - Fort Bragg, North Carolina

LOCATION: Fort Bragg Military Reservation, North Carolina 28307

OPERATOR: XVIII Airborne Corps and Fort Bragg

ADDRESS: Commanding General
XVIII Airborne Corps and Fort Bragg
Attention: Post Range Officer
Fort Bragg, North Carolina 82307
Telephone: 62170/66772/62900

AVAILABILITY REQUIREMENTS:

a. Who may use it - All DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Request submitted six weeks in advance
d. Time limitations - None

ALTITUDE LIMITATIONS:

a. Launch Altitude - 280 ft. MSL
b. Flight Altitude - Surface to 29,000 ft. MSL
c. Restrictions - Continuous

WEATHER CONDITIONS:

a. Temperature (approx.)
winter low 22°F Avg 42°F
summer high 100°F Avg 85°F
b. Wind (surface)
high 20 knots Avg 6 - 10 knots
c. General
Generally clear, some early morning ground haze in winter and frequent scattered afternoon thunder showers from late June through mid-August.

REMARKS:

Tethered balloons have been flown at Fort Bragg in the past. Based upon those past experiences, the flying of tethered balloons for experimental purposes could be accommodated. No facilities, instrumentation, photographic, or services are available to maintain balloons, equipment, and personnel.

RESTRICTED AREA R-5502 - Lacarne, Ohio

LOCATION: Camp Perry, Lacarne, Ohio

OPERATOR: State of Ohio

ADDRESS: Col. F. W. Conard
Superintendent Camp Perry
Port Clinton, Ohio 43452
Telephone: (419) 732-3501

AVAILABILITY REQUIREMENTS:

a. Who may use it - DOD sponsored projects
b. Priorities - DOD
c. Scheduling - Must be arranged
d. Time limitations - 0800 to 1600 local time

ALTITUDE LIMITATIONS:

a. Launch Altitude - 575 ft. MSL
b. Flight Level
   April 1 to May 31
      surface to and including 5000 ft. MSL
   June 1 to July 31
      surface to and including 34,000 ft. MSL
   August 1 to November 30
      surface to and including 5000 ft. MSL
c. Restrictions
   0800 to 1600 local time Saturday and Sunday April 1 through May 31

   0800 to 1600 local time daily June 1 through July 31

   0800 to 1600 local time Saturday and Sunday August 1 through November 30

   Other dates, times and altitudes (not to exceed 23,000 ft. MSL) by NOTAM, published at least 48 hours in advance.

WEATHER CONDITIONS:

a. Temperature (approx.)

winter low	-21°F	Avg	29°F
summer high	104°F	Avg	71°F

b. Wind (surface)

high	70 knots	Avg	10 knots

REMARKS:

Camp Perry is not a research and development area. It

is used primarly for reserve training camp. It is a large flat open area located on the shore of Lake Erie.

NCAR Scientific Balloon Flight Station, Palestine, Texas

LOCATION: Palestine, Texas

OPERATOR: Winzen Research, Incorporated for NCAR

ADDRESS: Alvin L. Morris, Manager
Scientific Balloon Facility
National Center for Atmospheric Research
Box 1470
Boulder, Colorado 80302

AVAILABILITY REQUIREMENTS:

The facilities and services are generally available to scientists from federal agencies, universities, and non-profit research organizations whose projects require balloon flights. The facilities are also available for company-sponsored test programs designed to improve scientific ballooning provided the results of such tests will be made available to NCAR and the balloon community.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 400 ft. MSL
b. Flight Level - See remarks
c. Restrictions - See remarks

WEATHER CONDITIONS:

a. Temperature (approx.)
   winter low 15°F Avg 40°F
   summer high 110°F Avg 92°F
b. Winds (surface)
   Not available

REMARKS:

The NCAR facility is not a restricted area. Therefore, all FAA regulations must be adhered to in order to fly a tethered balloon. The NCAR facility is used extensively for free balloon launchings.

Types of Support - Service to individual investigators who wish to take advantage of NCAR's complete services. NCAR provides launch, tracking, and recovery services from its fixed launch site. It also provides work space at the launch site, standard command and telemetry equipment, and balloon and helium purchasing service. The costs for facilities and services are borne by NCAR excepting for certain costs which are directly assignable to the investigator. These assignable costs are usually limited to the balloon and helium, but long-distance

phone calls and special services requested by an investigator may also be charged to his project.

Service to balloon operations groups of recognized competence, flying experiments for qualified investigators. These groups normally provide the launch, tracking and recovery services required for their flights, but limited tracking service can be provided by NCAR on request. Facilities are provided by NCAR and costs are allocated to these groups on virtually the same basis as to individual investigators.

Services to private companies operating for profit when a company wishes to carry out a test program designed to improve scientific ballooning. The company must satisfy NCAR that the test is likely to result in improved scientific ballooning and must make the results available to the scientific ballooning community as soon as possible after the test. Company projects which qualify are supported on the same basis as non-profit research flights.

Consulting Services - NCAR personnel at Palestine are available to discuss ballooning requirements with scientists. They review each request for ballooning service with the prospective user. They then advise how and when the flight can best be accomplished, what type and size balloon should be used, what auxiliary equipment (i.e., telemetry, stable platforms, etc.) will be necessary, and what the approximate cost will be to the user.

NCAR personnel will help select the appropriate balloon vehicle for the scientist's program by reviewing his proposed flight profile and requesting bids and specifications from balloon manufacturers. After reviewing the bids and specifications, the NCAR staff will recommend to the scientist the balloon which they believe will provide the most reliable vehicle for the flight.

Helium - Helium is available at the site through an independent contractor who invoices the scientist's parent organization directly.

Flight Priorities - As a general rule, field programs involving the largest number of personnel and having the most stringent operational and scientific requirements are given scheduling priority. Actual flight priority at the station is determined by the superintendent on the basis of readiness and suitable weather for a given flight.

For further information, call or write:

Superintendent
NCAR Scientific Balloon Flight Station
P.O. Box 1175
Palestine, Texas 75801
Telephone: (217) 729-6921

RESTRICTED AREA R-6604 - Chincoteague Inlet, Virginia

LOCATION: Three areas on Atlantic Coast of the Delmarva Peninsula:
1. The Main Base
2. The Wallops Island Launching Site
3. The Wallops Island Mainland

OPERATOR: Wallops Island is operated by NASA

ADDRESS: Director, Mr. Robert L. Krieger
Wallops Station
National Aeronautics and Space Administration
Wallops Island, Virginia 23337

AVAILABILITY REQUIREMENTS:

a. Who may use it and priorities - NASA programs normally do not need authorization.

Non-NASA should contact Director, Wallops Station to request authorization.

USAF or their contractors request authorization through Air Force, Systems Command Liaison Office at Langley Air Force Base, Hampton, Virginia

b. Scheduling - All users with authorization should notify Wallops Station of their plans as far in advance as possible

c. Time Limitation - Test station is available year round.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 0 ft. MSL
b. Flight Altitude - unlimited from MSL up
c. Restrictions - authorization and scheduling

WEATHER CONDITIONS:

a. Temperature (approx.)
   winter low -6°F Avg 58°F
   summer high 98°F Avg 63°F
b. Winds (surface)
   high 100 knots Avg 10 knots
   The wind direction is southerly during the summer and northwest during the winter.
c. General - The average annual precipitation is 37.03 inches. The climate is technically known as a "humid temperate climate with hot summers and no distinct dry seasons".

REMARKS:

Wallops Station, the only range facility completely owned and operated by NASA, is an operational base for launching vehicles as part of scientific experiments. The station is completely instrumented and has the facilities for almost every need. Wallops Station personnel can assist the teams of experimenters in flight preparation. It is primarily set up for rocket launchings and does not posses specific facilities for balloon launching, or equipment such as winches, cables, and helium. If specific equipment is necessary, Wallops Station should be contacted.

Churchill Research Range, Manitoba, Canada

LOCATION: Northeastern tip of Manitoba, Canada - West shore of Hudson Bay

OPERATOR: The Churchill Research Range (CRR) is at present jointly funded by the National Research Council of Canada (NRC) and the National Aeronautics and Space Administration of the United States (NASA). The onus of management of the range rests with NRC.

ADDRESS: Chief of Defense Staff
Canadian Armed Forces Headquarters
Ottawa, Ontario, Canada

Copy to:
Chief of Plans and Operations
Churchill Research Range
National Research Council
Fort Churchill, Manitoba
Canada
Telephone: (204) 675-2215

AVAILABILITY REQUIREMENTS:

Approval for use of CRR is controlled by a Joint Range Policy Committee (JRPC) on which NRC and NASA are represented. The JRPC meets as required.

ALTITUDE LIMITATIONS:

a. Launch Altitude - 25 ft. MSL
b. Flight Level - See remarks
c. Restrictions - See remarks

WEATHER CONDITIONS:

a. Temperature (approx.)

winter low	-57°F	Avg -25°F
summer high	95°F	Avg 63°F

b. Winds (surface)

high	120 knots	Avg 14 knots
Mean direction	NW 27	

REMARKS:

Fort Churchill is not a restricted area, therefore, operators must comply with the Air Regulations in Canada, or obtain exemptions from the Minister of Transportion. The purpose of CRR is to operate, maintain and develop a rocket range to support approved scientific agencies with comprehensive launch, instrumentation and data recovery facilities. Ground based observations and

research are also carried out at CRR. The range also supports scientific balloon launches on a non-interference basis.

Instrumentation Available - Comprehensive tracking, telemetering, communication, auroral observation, meteorology, workshop, photography, computer, office and rocket launching facilities are available. However, facilities are geared toward rocket-borne and ground observation research and are available for balloon support on a strictly non-interference basis only.

Photographic Equipment - 16mm operating at 8 - 64 fps
35mm operating at 8 - 48 fps
16mm operating at 4 - 48 fps

4 x 5 speed graphic
4 x 5 Linhoff
8 x 10 and 35mm cameras equipped with lenses of various focal lengths
Dark room

Laboratory and office space is available to approved scientific agencies.

All services are available on a non-interference basis. If any further information is required, write to:

Chief of Plans and Operations
Churchill Research Range
National Research Council
Fort Churchill, Manitoba
Canada

or

Department of Transport
Assistant Deputy Minister (General's Office)
Hunter Building
Ottawa, Ontario
Canada

REFERENCES

1. Haydon, F. S., Aeronautics in the Union and Confederate Armies, Vol. 1; Baltimore, Johns-Hopkins Press, 1941.

2. Cuneo, J. R., Winged Mars, Vol. I: The German Air Weapon 1870 - 1914, Harrisburg, Pa. Military Service Publishing Co., 1942; Vol. II: The Air Weapon 1914 - 1916, 1947.

3. Moedebeck, H. W. L., Pocketbook of Aeronautics, translated by W. M. Varley; London, Whittaker & Co. 1907.

4. Dollfus, C., The Orion Book of Balloons, New York, Orion Press, 1960.

5. War Department Technical Manual 1-325 Aerostatics, 1940.

6. Superintendent of Documents, U. S. Standard Atmosphere, 1962, U. S. Government Printing Office, Washington, D. C.

7. Brown, I.S.H. & Speed, L.A., Ballonet Kite-Balloon Design, Construction and Operation, R.A.E. Report No. Mech. Eng. 24 July 1962.

BIBLIOGRAPHY

AERODYNAMICS

Abbott, Ira H.: Airship Model Tests in the Variable Density Wind Tunnel. Report No. 394, Langley Memorial Aeronautical Laboratory, January 1931.

Air Corps: Test of 1/36-Scale Model of Goodyear Barrage Balloon for Both Deflated and Inflated Envelopes with Large and Small Fins. Technical Report No. 4744, March 1942.

Air Corps Material Division: Test of 1/37.5 Scale Model of Material Center Design Barrage Balloon No. X42K1783. Technical Report No. 4824

Allen H.J.: Estimation of the Forces and Moments Acting on Inclined Bodies of Revolution of High Fineness Ratio. NACA RMA9I26.

Anderson, A.A., Erickson, M.L., Froehlick, H.E., Henjum, H.E., Schwoebel, R.L., Stone, V.H., and Torgeson, W.L.: Lighter-Than-Air Concepts Study. General Mills, Inc., Minneapolis, Minnesota, Revised March 1960, Contract Nonr 1589(07), AD-236988.

Bairstow, L.: Applied Aerodynamics. London, Longman, Green and Co.; 1920. Discusses static equilibrium of kite balloons with fixed or running rigging, and derives equations of motion and cable derivatives.

Bairstow, L., Relf, E.F., and Jones, R.: The Stability of Kite Balloons: Mathematical Investigation. Advisory Committee for Aeronautics (England) Reports and Memoranda No. 208, December 1915.

Bateman, H. and Jones, L.J.: Forces and Moments on Kite Balloon Models Fitted with Various Types of Fins. Gt. Brit., ARC T. 3295(170); 9 August 1932. Basis for the modern British kite balloon; extensive comparative data. AD-223 734.

Bateman, H.: The Inertia Coefficients of an Airship in a Frictionless Fluid. California Institute of Technology Report No. 164, National Advisory Committee for Aeronautics, 1923.

Bishop, Robert P.: Flight Characteristics of the Type J-10 Balloon for Use with Retransmission Antenna Systems. Dynetronics Inc., Orlando, Florida, August 1958.

Blackburn, W.E.: Interim Engineering Report on Basic Performance on Non-Powered, Tethered Lighter-Than-Air Vehicles for Antenna Support. Kaman Aircraft Corp., Bloomfield, Conn., Report No. G-62, May 1954, Contract No. AF 30(602)-675, AD-41526.

Boatwright, D.W.: An Investigation of the Effect of Induced Nonsymmetric Pressure Distribution on the Aerodynamic Stability of an Airship Form. Aerophysics Dept., Mississippi State University, Office of Naval Research Contract NONR 978(02), Research Report No. 36, August 1961, AD-2622552.

Brown, D.W.: A Recording Technique for Kite Balloon Yaw Behaviour and Accelerations, and Some Experimental Results. Gt. Brit., R.A.E. Tech. Note No. Mech. Eng. 343; November 1961. Includes results of rigging at various incidence angles, and use of nose spoiler ring, enlarged vertical fins and ventral sail fin. AD-275 073.

Brown, I.S.H.: Notes of Stability of Kite Balloons. Royal Aircraft Establishment, Farnborough Department Memo ME 173, October 1957.

Durand, W.F.: Aerodynamic Theory -Vol. VI. Published by: Springer, Berlin, 1935.

Eckstrom, C.V.: Investigation of the Flight Characteristics of Free Flying Characteristics of Free Flying Aerodynamical Shaped Balloons. Schjeldahl Co. for NASA CR-66093, 1965 Contract NAS1-S271 NASA.

Emslie, A.G.: Balloon Dynamics. Technical Report #1 to Office of Naval Research, 1961.

Etkin, Bernard and Mackworth, Jean C.: Aerodynamic Instability of Non-Lifting Bodies Towed Beneath an Aircraft. University of Toronto Report UTIA TN65, January 1963.

Goodyear Aerospace Corporation, Akron, Ohio.: Tow-Model Tests (Quarter Scale) LTA-Support Vehicle for "Skyline" Project, GZ 347. General Electric Purchase Order No. 211-524-25018, GER-10441, October 1961.

Havill, Clinton H.: The Drag of Airships. Technical Note No. 247. National Advisory Committee for Aeronautics (1923-1925).

Hess, Joseph: Statistics of Parameters Affecting Tethered Balloon Flights. Air Force Surveys in Geophysics No. 182. AFCRL, June 1966.

Hoerner, Sighard F.: Aerodynamic Drag. Published by Author, 1951,

Journal of Aeronautical Sciences, Volume No. I.: Sphere Drag Determined by Coasting Through Still Air.

Kaman Aircraft Corp.: Interim Engineering Report on the Response of a Kytoon to Vertical and Horizontal Gusts. Bloomfield, Conn. Report No. G-68, Contract AF30(602)-675; August 12, 1954. (Confidential Report, declassified 1966) (RADC T.N. 54-347) AD-57 119.

Kaman Aircraft Corporation: Response of a Kytoon to Vertical and Horizontal Gusts: Bloomfield, Conn. Contract No. AF30(602)-675, August, 1954, AD-57119.

Law, E.H.: The Longitudinal Equations of Motion of an Air-borne Towed Vehicle Incorporating an Approximation of Cable Drag and Inertia Forces. U.S.N. Air Development Center, Johnsville, Report 687, 1964.

Lum: A Theoretical Investigation of the Body Parameter Affecting the Open Loop Pitch Response of a Submerged Towed Body. David Taylor Model Basin Report 1369, 1960.

MacCready, Jr. and Jex, H.R.: Study of Sphere Motion and Balloon Wind Sensors. NASA TM X-53089, July 1964.

Munk, Max M.: The Aerodynamic Forces on Airship Hulls. Report No. 184. National Advisory Committee for Aeronautics, 1924.

Munk, Max M.: Notes on Aerodynamic Forces - I Rectilinear Motion. Technical Note No. 104. National Advisory Committee for Aeronautics, July 1922.

Munk, Max M.: Notes on Aerodynamic Forces - II Curvilinear Motion. Technical Note No. 105. National Advisory Committee for Aeronautics, July, 1922.

Murk, Sanger M., Jr. and Ware, George M.: Static Aerodynamic Characteristics of Three Ram-Air-Inflated Low-Aspect-Ratio Fabric Wings. LWP-254, Langley Research Center, July 1966.

Murrow, H.N. and Henry, R.M.: Self Induced Balloon Motions. Fifth Conference on Applied Meteorology, Atlantic City, N.J., March 2-6 1964 Paper.

Pannell, J.R.: Notes on French and Italian Aeronautical Practice with Particular Regard to Airships. G. Brit., ARC, R&M 692; March 1919. Includes about a page on French expanding-gore kite balloons.

Patton, K.T. and Schram, J.W.: Equations of Motion for a Towed Body Moving in a Vertical Plane. Underwater Sound Laboratory, USN Report 736, June 1966.

Potter, R.C.: The Stability of Captive Balloons for Instrument Flying, Including Analysis of Multi-Cable Configurations. Wyle Labs - Research Staff Report WR 65-28, Contract NAS8-5384; November 1965. Excellent analysis, but leaves solution to a computer trial-and-error scheme with subsequent interpolation. N67-11729.

Rizzo, Frank: A Study of Static Stability of Airships. Technical Note No. 204. National Advisory Committee for Aeronautics, September 1924.

Scholkemeier, F.W.: Six Components Measurements on a Balloon with Two Various Tails. Report ATI25-416; 20 April 1943. Translated German Technical Report on type K WW II barrage balloons.

Scoggins, J.R.: "Spherical Balloon Wind Sensor Behavior" Journal of Applied Meteorology, February 1965.

Sherburne, Paul A.: Wind Tunnel Tests of Natural Shape Balloon Model. Goodyear Aerospace Corp., Akron, Ohio. AFCRL Contract No. F19628-27-C-0145. AFCRL No. -68-D123, March 1968.

Simonds, M.H.: Low Speed Wind Tunnel Tests on a Kite Balloon Model. G. Brit., Ministry of Aviation, A.R.C. Current Papers No. 643; November 1961 (published 1963). Static forces and moments and some stability derivatives.

Tuckerman, L.B.: Notes on Aerodynamic Forces on Airship Hulls. Technical Note No. 129. National Advisory Committee for Aeronautics, March 1928.

University of Detroit, Aeronautical Laboratory.: Wind Tunnel Test of the General Mills Aerocap Model. Part I, II, and III Project 314. March, 1960.

Warner, Edward P. Aerostatics. The Ronald Press Co., New York, 1926.

Waters, M.H.L.: Proposed Experiments on the Behaviour of Kite Balloons. Gt. Brit. R.A.E. Tech. Note No. Mech. Eng. 306; December 1959. Similitude requirements for experiments on inflatable models in free air (towing tests). AD-234 633.

Waters, M.H.L.: Some Observations on the Wander of a Kite Balloon. Gt. Brit. R.A.E. Tech. Note No. Mech. Eng. 305; December 1959. Camera obscura observations, with results for velocity, accelerations, and side-slip angles. AD-235 480.

Watson, C.D.: Auto-stabilization of Kite Balloons. R.A.E. Dept. Memo No. M.E. 192 (Restricted) R.A.E. Great Britain, May, 1958.

Wieselsberger, C.: Further Information on the Laws of Fluid Resistance. Technical Note No. 121, National Advisory Committee for Aeronautics, December 1922.

Winny, H.F.: Vortex System Behind a Sphere Moving through Viscous Fluid. Aeronautical Research Committee Reports and Memoranda No. 1531, September 1932.

Young, D.W.: Test of Material Division Barrage Balloon Model with Three Different Tail Arrangements. Report No. 4636. Test No. 253 (5 Ft. Tunnel) Material Division, Dayton, Ohio, May, 1941. ATI37264.

Zahm, A.F., Smith, R.H. and Hill, G.C.: The Drag of C Class Airship Hull with Varying Length of Cylindric Midships. Report No. 138, Bureau of Construction and Repair Navy Department, National Advisory Committee for Aeronautics.

Zahm, A.F.: Flow and Drag Formulas for Simple Quadrics. National Advisory Committee for Aeronautics, 1927.

BALLOON APPLICATIONS

Banks, William O. Capt. USAF.: Low-Level, Fine-Scale Wind Determination by Captive Balloons. APGC Tech. Doc. Rep. No. APGC-TDR-64-24, May 1964, AD 601944.

Burns, A.: Power Spectra of the Vertical Component of Atmospheric Turbulence Obtained From Concurrent Measurement of an Aircraft and at Fixed Points. Royal Aircraft Establishment (Farnborough), Tech. Note Structures 325, January 1963, AD-406118.

Compressed Air Magazine: "Ballooning for Tuna". March 1966, p. 11 (article)

Goodyear Aerospace Corporation, Akron, Ohio: Preliminary Study of Fixed Base Installations For Balloon Antenna Support. April 1962. GER 10638, Seq. No. 44939.

Hall, M.P.M. and Gardiner, G.W.: "A Psychrometer Radiosonde Developed for Determining Radio Refractive Index As A Function of Height". Journal of Scientific Instruments (Journal of Physics E) 1968, Series 2, Vol. 1, pp 401-405 (article)

Kaman Aircraft Corp.: Interim Engineering Report on Basic Performance of Non-Powered, Tethered Lighter-than-air Vehicles for Antenna Support. Bloomfield, Conn. Report No. G-62, Contract AF30(602)-675; May 7, 1954. (Confidential report, declassified 1966). Includes tripod-tether results. AD-41 526.

Keay, C.S. and Gray, R.E.: "A Simple Balloon Technique for Measuring the Radiation Patterns of Radio Aerials" Electronic Engineering, Vol 36, pp 322-325, May 1964.

Kretow, Michael, S.: Application of a Tethering System to a Specific Requirement In 1964 Symposium Proceedings. Tripod-tether balloon for Surveyor drop tests at Holloman AFB.

Leppert, M.L., Shanahan, F.J., and Worsley, D.A.: Balloon-Elevated Antennas. Naval Research Lab. Report 4490; 10 February 1955. 100 ft emergency antenna tests on ice-breakers in Arctic, using Dewey & Almy Kytoon, Goodyear single-hull balloon, and one or two Jalbert JX-7s. AD-56 660.

Litton Systems, Inc.: Lightweight Flexible VHF Tree-Top Antenna with Inflatable Mast. Applied Science Division Report No. 2940; 28 February 1966. Final Report on Contract DA28-043-AMC-00335(E). In spite of title, the major part of report deals with a VHF antenna supported by an AEROKITE balloon, with favorable field test results. AD-633 254.

MacFadden, John A.: Tethered Balloons - Their Uses in Industrial Applications. G. T. Schjeldahl Company, Northfield, Minn. 12th National SAMPE Symposium, AIAA.

Menke, James A.: Capabilities of Captive Balloon Systems, in Proceedings of the AFCRL Scientific Balloon Symposium, 1963: Air Force Surveys in Geophysics No. 154, AFCRL-63-919; December 1963. Gives aerostatic and aerodynamic characteristics of Viron tethered balloons of Navy Class-C shape. Discusses support equipment, operating considerations, and tandem balloons. AD-614 065.

Pohl, Russell A.: The Applications of Hot-Air Balloons to Scientific Programs, Raven Industries, Inc., Sioux Falls, South Dakota. AFCRL-63-919, Dec. 1963.

Samuels, David W.: Analysis of Balloon-Borne Communications Systems. U.S. Army Limited War Lab. Tech. Memorandum 64-04: September 1964. Discusses various VHF transmission lines as tethers for small balloons at about 500 feet. AD-448 720.

Shamburger, Page: "Spectacular Air Rescue By Skyhook". Air Progress, February 1968, pp 33-36 (article).

Silbert, Mendel N.: Use of a Captive Balloon in the Aeropalynologic Survey Project. NASA Wallops Station, Wallops Island, Virginia, AFCRL Tethered Balloon Workshop, October 1967.

Steele, J. G.: Measurement of Antenna Radiation Patterns Using a Tethered Balloon. IEEE Transactions on Antennas and Propagation, Vol. AP-13, No. 1, pp. 179-180, January 1965.

Strom, C. A. and Lawrence, C.N.: Balloon-Supported Platforms in Communications in 1964 Symposium Proceedings. Both tethered and free-floating balloons are discussed as supporting platforms for both active and passive radio repeater stations.

Sumner, P. H. Capt.: The Science of Flight and Its Practical Application. Vol. I, Airships and Kite Balloons, London, Crosby, Lockwood & Son. 1926. Much more limited than Chandler of same date.

Winker, James A.: Technological Applications of the Modern Montgolfier. Raven Industries, Inc., Sioux Falls, South Dakota, AIAA A68-20908.

Final Report, Balloon Borne Radio Communication System. 10 April 1965. U.S. Army Concept Team in Vietnam. For Official Use Only. Field results using a number of 400-cubic foot Vee-Balloons. AD-466 186.

BALLOON SYSTEMS

Artuso, N., Mason, H., Towless, R., Wezner, F., and Krevsky, S.: Tactical Jungle Communications Study. Surface Communications Systems Laboratory, Interim Report DA-36-039-AMC-00011(E), March 1963, AD-445943

Brown, I.S.H. and Speed, L.A.: Ballonet Kite Balloons Design, Construction and Operation. Royal Aircraft Establishment, Report Mech. Eng. 24, July 1962, AD290-765

Brown, I.S.H.: Development of the Ballonet Kite Balloon. Gt. Brit. R.A.E., Tech. Note No. Mech. Eng. 328; October 1960. Technical history, to some extent included in Speed's Workshop paper. AD-250 553.

Continental Electronics Manufacturing Co.: Tethered Balloon-Antenna System Flight Operations Summary Report. Sub Contract 70551 G.T. Schjeldahl Company Inv. No. 10742, February 1967.

Davies, V.A., and Watson, C.D.: Balloon Suspension Characteristics. (U) Gt. Brit. R.A.E. Departmental Memorandum No. ME 62; March 1955. (Confidential-MHA and U.K. Restricted) Design of a tandem balloon and cable for supporting a weighted shell at a particular altitude in winds up to 60 mph steady with gusts to 85 mph. AD-302 716L.

Dimmig, Howard L.: Service Test of Kytoon. APGC Eglin AFB, Report PN-3-47-6; 20 August 1947. Concludes that kytoon is not functionally superior to M-278 balloon for supporting antenna of Radio Set AN/CRT-3 in life rafts. ATI-64-269.

Edwards, C.P.: Boundary Layer Profile Measurement System. E. Bollay Associates, Inc., Boulder, Colorado, NCAR Technical Note NCAR-TN-16, March 1966 and NCAR Technical Note NCAR-TN-17, March 1966.

Elliot, Sheldon D., Jr.: Tethered Aerological Balloon System. Technical Progress Report 398, U.S. Naval Ordnance Test Station, China Lake, California, September 1965, AD621959.

Engineer Board, Fort Belvoir, Va.: Photographic Report of the Projects of the Barrage Balloon Branch from April 1942 to September 1943. Project No. BBS-670, October 1943

Ferguson, William R., Capt., USAF: AFCRL Tethered Balloon Programs. AFCRL Bedford, Massachusetts, Proceedings, AFCRL Scientific Balloon Workshop 1965, AFCRL-66-309, May 1966 Special Report No. 45.

Goodyear Aerospace Corporation, Akron, Ohio: Balloon Borne Communications Systems Final Progress Report. Contract DA-18-001-AMC-638(X), GER-11987.

Goodyear Aerospace Corporation, Akron, Ohio: Dynamic Lift Tethered Balloons. June 1967, ARD-10699.

Goodyear Aerospace Corporation, Akron, Ohio: Flight and Shed Test on 6000 cu. ft. Balloon. October 1950, GER 2349, Seg. No. 12439

Goodyear Aerospace Corporation, Akron, Ohio: Instruction Manual for the Captive Balloon Borne Communications System. For: U.S. Army Limited War Laboratory

Goodyear Aerospace Corporation, Akron, Ohio: Operation and Handling Instructions for 6000 cu. ft. Balloon (Single Hull). April 1968, GER 13820.

Goodyear Aerospace Corporation, Akron, Ohio: Operation and Handling Instructions Fort Monmouth 8000 cu. ft. VEE-Balloon. August 1967, GER-13435.

Goodyear Aerospace Corporation, Akron, Ohio: Operation and Maintenance Instructions Mobile LTA Vehicle (TVLF) Model GZ349. Contract NObsr 93355, January 1966 Report, GER 12586.

Goodyear Aerospace Corporation, Akron, Ohio: Tandem Barrage Balloon Tests, Part I, II, III, GER 1185, Seg No. 30440, Air Corps Contract No. W535ac23601, 1942.

Goodyear Aerospace Corporation, Akron, Ohio: 300 Cubic Foot Model 'VEE-Balloon' Flight Tests with Launch-Area Screen. Seg. No. 45674, June 1962.

Goodyear Aerospace Corporation, Akron, Ohio: VEE-Balloon. Report GER 11082, August 1963.

Goodyear Tire and Rubber Co., Akron, Ohio: Erection, Operation, and Maintenance Handbook - Navy Model ZK2G Captive Balloons. February 1946.

Goodyear Tire & Rubber Co., Akron , Ohio: Handbook of Operation and Service Instructions for the Type D-7 Low Altitude Barrage Balloon. Seg. No. 31941, Air Corps. Contract W535ac 24563, 1942.

Honeywell Aeronautical Division: Balloon Borne Oil Field Surveillance System. Proposal 48-5-100, 1962.

Johnson, J.M.: Balloon Engineering Design Manual. General Mills, Inc., Aeronautical Research Laboratory, Minneapolis, Minnesota, ATI 179-857.

Laursen, H.G.: Operation ROLLER COASTER Project Officers Report -- Project 2.7, Balloon Support. POR-2510(WT-2510); May 1965. Sandia Corporation, Albuquerque, N.M. Very similar to Laursen's Workshop paper. AD-462 450.

Ledokhovich, A.A.: Balloon-Borne Electric Meteorograph. Leningrad. Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 154: 105-108, 1964. Translated by American Meteorological Society for AFCRL; Dec. 1965. The design of this balloon-borne meteorograph includes a special cable that transmits the data directly to the ground. AD-630 688.

Leppert, M.L., Shanahan, F.J., and Worsley, D.A.: Balloon-Elevated Antennas. Communications Branch Radio Division, Naval Research Laboratory, Washington, D.C., NRL Report 4490, February 1955, AD-56660

Lewis, Glenn W.: Balloon Borne Radio Communication System. Army Concept Team in Vietnam, APO 143, San Francisco, California, April 1965, AD-466 186.

Longden, G.B., M.A.: Some Characteristics of Kite Balloons as Targets for Guided Weapons. Royal Aircraft Establishment (Farnborough), Technical Note G.W. 242, April 1963 (Confidential) AD-12542.

Martin, Gruver H.: Feasibility Study of a Balloon Skyhook. United States Naval Ordnance Lab., White Oak, Maryland NOL TR 67-191, December 1967, AD-827280.

Menke, James A.: Capabilities of Captive Balloon Systems. Viron Division G.C.A., AFCRL Scientific Balloon Symposium, September 1963.

Navy Department, Bureau of Construction and Repair: The Type 'M' Kite Balloon Handbook. Government Printing Office, Washington, D.C., 1919.

Payne, James C.: Balloon Recovery System. Proceedings, AFCRL "Scientific Balloon Workshop 1956", AFCRL Report No. 66-309, May 1956.

Samuels, David W.: Analysis of Balloon-Borre Communications Systems. U.S. Army Limited War Lab., Technical Memorandum 64-04, September 1964, AD-448 720.

Special Air Warfare Center, Eglin AFB, Florida: Evaluation of the Ground-To-Air Balloon Station Recovery System - Phase II - With C-47 Type Aircraft. Report No. SAWC-TDR-63-9, September 1963, AD-420811.

Struble, Dewey: Project NIP Final Report on the Dual Diagnostic Balloon Arrays for the AJAX Event. By: Sea-Space Systems, Inc., Report SSS 4069, December 1966.

Tsaig, M.: Barrage Balloons. Samolet (The Aeroplane) USSR, Vol. 17, No. 23-24; Dec. 1940, pp. 30-32. R.T.P. Translation No. 1289, issued by Ministry of Aircraft Production. History and descriptions of foreign types, photos of British, French, and German balloons, WWII.

U.S. Army Air Corps Technical Regulations No. 1170-215: Balloons and Accessories. Washington, May 20, 1929. Mainly on standard C-3 observation balloon (type R Caquot).

Weidner, George E.: Ballonet Type, Very Low Altitude Barrage Balloon. Report No. 839, The Engineer Board, Fort Belvoir, July 1944.

Widmer, Emil J.: Military Observation Balloons (Captive and Free). Van Nostrand (New York), 1918. Based on Balloon Manual of the German Army, dealing mainly with Drachen type.

Winker, James A.: Tethered Hot Air Balloons. Raven Industries, Inc., Sioux, South Dakota, Engrg. Tech. Note 50, October 1967. Paper given at 1967 AFCRL Tethered Balloon Workshop.

Fulton Aerial Recovery System for C-123 Aircraft. TAC TR-64-24, I CAG Project 2D-7, June 1965.

Operational Test and Evaluation Recovery Balloon Deflation Systems. TAC TR-66-1-M-1, I CAG Project 2D-33, April 1968.

CABLES

Alekseev, N.I.: "On the Equilibrium Shape and Tension of a Flexible String Acted Upon by External Forces That Are Functions of the Orientation of the String in Space". PMM, v 28, n 5, pp 949-951; 1964. Translated as Journal of Applied Mathematics and Mechanics. General three-dimensional solution (in quadratures) for, e.g., string in a space curve in wind and gravity field.

Anderson, G.F.: "Optimum Configuration of a Tethering Cable" Journal of Aircraft, Vol. 4 - No. 3, May-June 1967, pp. 261 - 263.

British Advisory Committee for Aeronautics: The Form of a Heavy Flexible Cable Used for Towing a Heavy Body Below an Aeroplane. Reports and Memoranda, 1952. February 1934.

Brown, I.S.H.: Development of an 18 Ton Wire Rope Enclosing an Electrical Power Cable. (U), Gt. Brit. R.A.E. Tech. Note No. Mech. Eng. 307; January 1960. (Confidential-MHA report) Successful development of a wire cable carrying heavy power leads with good strength/weight and fatigue life. AD-317 047L.

Bryant, L.W., Brown, W.S. and Sweeting, N.E.: Collected Researches on Kites and Towed Gliders. Rand M 2302, 1950.

Burton, Michael B. and Passmore, Harry, III.: On the Stability of Airborne Towed Vehicles. U.S. Naval Air Development Center, Johnsville, Pennsylvania Report No. 607, May 1962. Contract N62269-1369.

Claassen, R.W. and Thorne, C.J.: Steady-State Motion of Cables in Fluids. Part 2 Tables of Cable Functions for Vertical Plane Motion. Test Data Division, Pacific Missile Range, August 1963, AD-429873.

Cushman, G.S.: Cable Fairing Phase Report. Naval Airship Training and Experimentation, January 1949.

DeFoe, George L.: Resistance of Streamline Wires. Technical Notes No. 279. Langley Memorial Aeronautical Laboratory, March 1928.

Genin, I. and Cannon, T.C.: "Equilibrium Configuration and Tensions of a Flexible Cable in a Uniform Flowfield" Journal of Aircraft, Vol. 4 - No. 3, May-June 1967, pp. 200-202.

Glauert, H.: The Stability of a Body Towed by a Light Wire. Rand M 1312 (Ae451), February 1930.

Great Briton Report: On the Action of Wind on Flexible Cables, with Application to Cables Towed Below Aeroplanes and Balloon Cables. Great Britain Report and Memorandum 554, October 1918.

Hanna, G.L.: Mechanical Testing of Glass-Epoxy and Steel Cables - Final Report. Monsanto Research Corp., for Wright-Patterson AFB, Ohio, October 1967. Contract No. NrF33615-67-C1315.

Hoerner, S.F.: Fluid Dynamic Drag. Published by Author. Midland Park, New Jersey, 1958.

Hofer, P. H., Nalepa, H.J.: Composite Thermoplastic/Glass Filament Reinforcement For Buoyant Submarine Cables RG-372(XN-1)/u and RG-373(XN-1)/u. Research and Development Dept., Union Carbide Chemicals and Plastics Division, Bound Brook, New Jersey. February 15, 1968.

Lafon, Charles, Commandant: Etude sur le Ballon Captif et les Aeronefs Marins. Gauthier-Villars et Cie (Paris), 1922. Includes wind force on cable and effects of motion of tethering points, i.e., on a naval vessel.

Laudweber, L. and Grimminger, G.: Orientation and Position of a Heavy Body Suspended in a Uniform Current by a Flexible Cable. DTMB Report R-37, August 1941.

Landweber, L. and Protter, M.: "The Shape and Tension of a Light Flexible Cable in a Uniform Current". Journal of Applied Mechanics, June 1947, pp. A-121-A-126 also, DTMB Report 533, October 1944.

McKee, R.B., Jr. and Herzog, S.H.: Tether for a High Balloon. 12th National SAMPE Symposium, AIAA No.

Merritt, P.H., 1st Lt. USAF and Cunningham, D.K. 1st Lt. USAF: Some Aerodynamics Characteristics of Tow Targets and Towlines. Air Proving Ground Center, Eglin AFB, Florida AD-471840.

Moore, G.T.: Technical Note Towed Bird Dynamic. U.S. Naval Air Development Center, Report No. NADC AW-N-61111, October 1961, AD-267879.

Morgan, P.G.: A Note on the Drag Force on Wires. Applied Science Research, Sec. A 15, 1966.

NAVWEPS Report 9051: Development of a Glass-Reinforced Resin-Bonded Cable of Continuous Length, Supplement 1. NOTS, China Lake; June 1966. Supplement 1, NOTS TP 4133. Merits of using "cake" single-end glass fiber are discussed, and production of lengths up to 96,000 feet. AD-811 339.

Neumark, S.: Equilibrium Configuration of Flying Cables of Captive Balloons, and Cable Derivatives for Stability Calculations. G. Brit. Min. of Aviation, ARC R&M No. 3333; June 1961 (pub. 1963). Carries Pippard's derivation through non-lifting (spherical balloon) and no-change-of-incidence (kite balloon) cases, and indicates natural modes for a general-case coupled-mode solution, including effects of cable drag. AD-365 331.

Ohio Brass Co.: Summary of Voltage Tests in GLASTRAN Cable: Wet and Dry 60-cps, 200,000+ Volts Flashover-Tracking Report. For: Packard Electric Division, General Motors Corporation, Warren, Ohio, August 22, 1966.

Packard Electric Division, General Motors Corporation: Electrical Leakage or Tracking of GLASTRAN Cables. Warren, Ohio May 1, 1967.

Packard Electric Division, General Motors Corporation: GLASTRAN Cables on Pulley Tests Under Cyclic Reversing and Drop-Load Impact. Warren, Ohio, April 12, 1967.

Packard Electric Division, General Motors Corporation: 'GLASTRAN' Urethane Jackets and Their Outdoor Aging Characteristics. Warren, Ohio, May 1, 1967.

Patton, Kirk T., and J.W. Schram.: Equations of Motion for a Towed Body Moving in a Vertical Plane. U.S. Navy Underwater Sound Laboratory Report No. 736; 15 June 1966. Independent derivation, includes cable mass and derivatives and forcing motion at towing point, gives simple computer program for solutions. A number of useful references to the underwater-towing literature. AD-635 214.

Phillips, W.H.: Theoretical Analysis of Oscillations of a Towed Cable. NACA TN 1796, January 1949.

Pode, Leonard: A Method of Determining Optimum Lengths of Towing Cables. DTMB Report 717, April 1950. (Supplement published in March, 1956.)

Pode, Leonard: Tables for Computing the Equilibrium Configuration of a Flexible Cable in a Uniform Stream. DTMB Report 687, March 1951. (Supplement published in September 1955).

Potter, R.C.: The Stability of Captive Balloons for Instrument Flying, Including Analysis of Multi-Cable Configurations. Wyle Laboratories - Research Staff. Report No. W.R. 65-28, November 1965.

Reid, Walter P.: Stability of a Towed Object. U.S. Naval Ordnance Laboratory. Mathematics Department Report No. M52, October 1964, AD-447154.

Relf, E.F. and Powell, C.H.: Tests on Smooth and Stranded Wires Inclined to the Wind Direction, and a Comparison of Results on Stranded Wires in Air and Water. Aeronautical Research Committee Rand M307, January 1917.

Ringleb, F.O.: "Motion and Stress of an Elastic Cable Due to Impact". Journal of Applied Mechanics, March 1957, pp 417-425.

Rust, T. and Jopson, H.B.: Evaluation of Titanium Alloy Cables for Aircraft Use. NADC Johnsville Report No. NADC-AM-6709; 17 March 1967. Tested in fatigue for use as aircraft control cable or helicopter hoist cable; one alpha-beta and two all-beta cables all had poor fatigue life. AD-811 897. Limited distribution.

Schjeldahl, G.T. Company: Report of Mechanical Tests on GLASTRAN Balloon Antenna-Type Cable. P.O. 61-38899. For: Packard Electric Division, General Motors Corp., Warren, Ohio, July 1967.

Soldate, A.: Dynamic Analysis of the Tethering Cable Portion of a High Altitude Tethered Balloon System under Fully Deployed Conditions. National Engineering Science Co., Report S-344; October 1966. Final Report on Contract N00014-66-C0187, Order No. 756. Computer study: tentative conclusion is that 100,000 ft glass-fiber/resin type cable is suitable. AD-651 024.

Soviet: Glazed Frost and Ice Formation on Cables Within the Territory of the USSR. Translations of Soviet-Bloc Scientific and Technical Literature, July 28, 1964, AD-603535.

Starkey, W. L. and Cress, H.A.: "An Analysis of Critical Stress and Mode of Failure of a Wire Rope". "Journal of Engineering for Industry", Page 307, November 1959, ASME.

Stevens, G.W.H.: Factors Affecting the Design of a System for Towing a Body on a Long Length of Wire. Royal Aircraft Establishment (Farnborough), September 1962, AD-296137.

Taylor, David. Model Basin: A Fortran Program for the Calculating of the Equilibrium Configurations of a Flexible Cable in a Uniform Stream. Report 1806, March 1964.

Wald and Quentin: Interim Engineering Report on an Analysis of the Forces in a Flexible Cable Subject to Wind and Gravity. Kaman Aircraft Corp., Bloomfield, Connecticut, Report No. G-61, April 1954.

Walton, T.S. and Polacheck,H.: Calculation of Nonlinear Transient Motion of Cables: David Taylor Model Basin Report 1279, 1959. A condensed paper is given in "Mathematics of Computation" (The Siam Review) No. 69-72, 1960, pp 27-46.

Whicker, L.F.: The Oscillatory Motion of Cabled-Towed Bodies. University of California. Institute of Engineering Research, Berkeley, California. May 1, 1957, AD135265.

Woodward, W.C.: Aerial Tow Target System Studies Final Report. U.S. Naval Air Development Center, Johnsville, Pennsylvania, June 1966. Report No. NADC-ED-6640.

Commissariat a l'Energie Atomique: High-Altitude Measurements on Natural Radioactivity (Mesure de la Radioactivite Naturelle de l'Air en Altitude a l'Aide d'un Ballon Captif). Grenoble (France). Centre d'Etudes Nucleaires. 5 p in French; 1965. N67-23731.

Conley, William F.: High Altitude Tethered Balloon Design. Goodyear Aerospace Corporation, Akron, Ohio, Goodyear Engineering Report GER-13501, October 1967.

Conley, William F.: High Altitude Tethered Balloon System Study. Goodyear Aerospace Corporation, Akron, Ohio, Task Report No. 3 GER-13667, ARPA Contract F19628-67-C-0145, January 1968.

Doyle, George R. Jr.: Mathematical Model for the Ascent and Descent of a High Altitude-Tethered Balloon. Goodyear Aerospace Corporation, Akron, Ohio, GER-13840, July 1968. Prepared for Second Aerodynamic Deceleration Systems Conference of AIAA at El Centro, Calif.

Elliot. Shelden D., Jr.: Tethered Aerological Balloon System. U.S. Naval Ordnance Test Station, China Lake, California, Technical Progress Report 398, September 1965, AD 621-959.

Goodyear Aerospace Corporation, Akron, Ohio: Configuration Trade-Off Study for a High Altitude Tethered Balloon System. For Sylvan Ginsbury, Ltd., New York City, New York, GER-13760, March 1968.

Goodyear Aerospace Corporation, Akron, Ohio: Feasibility Study, High-Altitude Tethered Balloon System for Advanced Research Projects Agency. Technical Report GER-11287, ARPA Contract SD-199, October 1963.

Menke, James A.: High-Altitude Tethered Balloon Systems Study. Goodyear Aerospace Corporation, Akron, Ohio, Task Report No. I, GER-13260, ARPA Contract F19628-67-C-0145, May 1967.

Molded Latex Products, Inc., Patterson, New Jersey: High Altitude Balloon Research and Development - Fourth Quarterly Report. Signal Corps Contract No. DA-36-039-ac-4, Project No. 172-B, July 1950.

Vitro Laboratories Division of Vitro Corporation of America: One-Hundred-Thousand Foot Tethered Balloon Feasibility Study (U). Technical Report TR01830.01-1, ARPA Contract SD201, October 1963. (Confidential)

Vorachek, Jerome: Concept for an Extremely High Altitude Tethered Balloon System. Goodyear Aerospace Corporation, Akron, Ohio, GER-13812, July 1968.

Vorachek, Jerome: High Altitude Tethered Balloon System Study. Goodyear Aerospace Corporation, Akron, Ohio, Task Report No. 2, GER-13552, ARPA Contract F19628-67-C-0145, November 1967.

Vorachek, Jerome: High Altitude Tethered Balloon Systems Study. Goodyear Aerospace Corporation, Akron, Ohio, Task Report No. 5 GER-13790, ARPA Contract F19628-67-C-0145, March 1968.

LOGGING BALLOONS

Goodyear Aerospace Corporation: Balloon Logging Systems: Phase I - Analytical Study; Phase II - Logistics Study. 1964. Contract 19-26 with Forest Service, U.S. Dept. of Agriculture. Thorough analysis and discussion in two volumes. Compares single-hull and Vee-Balloon technically and logistically.

Goodyear Aerospace Corporation: Logging Balloon Configurations. Analysis for U. S. Forest Service Proposed Phase III Program. GER-11823, November 1964.

Lysons, Hilton H. et al.: Logging Test of a Single-Hull Balloon. U.S. Forest Service Research Paper PNW-30; 1966. Field tests, time study, conclusions.

Mann, Charles N.: Forces in Balloon Logging. U.S. Forest Service Research Note PNW-28; August 1965. Brief analysis of static, aerodynamic, and inertia loads.

Pohl, Russell A.: The Use of a Tethered, 15,000 Pound Gross Lift Natural Shaped Balloon for Remote Logging Operations. Raven Industries, Inc., Sioux Falls, South Dakota, October, 1967. Paper given at 1967 AFCRL Tethered Balloon Workshop.

Stein, D.E. and Shindo, S.: A Wind Tunnel Test of a Single Hulled Balloon at Extreme Angle of Attack. University of Washington Aeronautical Lab. UWAL 901, February 1968.

Swarthout, Colburn D.: Aerodynamic Forces on Logging Balloon. MS Thesis, U. of Washington, 1967. Sponsored by U.S. Forest Service. Drag, lift, and moments from wind-tunnel tests of Vee-Balloon and Class-C balloon models, and longitudinal and vertical added masses from water oscillations tests.

Wood, Nat:"Factory in the Forest". Machine Design, November 9, 1967, pp 20-29.

MISCELLANEOUS

Bird, W.G.: The Influence of Atmospheric Humidity and Other Factors Upon the Static Lift of Airships. The Royal Aeronautical Society, 1931.

Electro-Mechanics Company, Austin, Texas: Balloon Handling Technique. Contract No. AF 30(602)-1884, November 1959. Project No. 4540, Task No. 45166, Interim Report No. 1.

Ferguson, W.R.: AFCRL Tethered Balloon Programs. AFCRL-66-309, Air Force Cambridge Research Laboratories, May 1966.

Green, Roger E.; U.S. Bureau of Commercial Fisheries: "Balloons For Marine Observations". Sea Frontier, pp 130-137.

Haydon, F. Stansburg: Aeronautics In the Union and Confederate Armies. with a survey of military aeronautics prior to 1861, The Johns Hopkins Press, 1941.

Hess, Joseph: Statistics of Parameters Affecting Tethered Balloon Flights. July, 1966. Air Force Surveys in Geophysics, No. 182, AFCRL-66-480. Climatological statistics of parameters affecting tethered balloon flights are presented for a proposed tethered balloon project at Key West, Florida. AD 637853.

High Voltage Lab., General Electric Company, So. Pittsfield, Mass.: A Feasibility Study of Improved Lightning Protection Systems. U.S. Naval Civil Engineering Lab., Contract No. NBy-32260, Report No. 64PT146, August 1964, AD-451034.

Ingram, David M., Major USAF and Gullion, Jimmie L, T. Sgt. USAF: Estimated Frequencies of Potential Icing Conditions at Specified Altitudes. Air Weather Service (MATS) USAF, Tech. Report 182, September 1964, AD-448047.

Kelly, T.W., editor: Proceedings AFCRL Tethered Balloon Workshop. AFCRL-68-0097, Air Force Cambridge Research Laboratories, March, 1968.

Lysons, Hilton H.: Compatibility of Balloon Fabrics with Ammonia. Forest and Range Experiment Station, Portland, Oregon, U.S. Forest Service Research Paper, PNW-42, September 1966.

Ross, R.S.: A New Material Capability for the Balloon Field. in Proceedings 1964 AFCRL Scientific Balloon Symposium; Air Force Surveys in Geophysics No. 167, AFCRL-65-486; July 1965. Discusses use of Goodyear AIRMAT in tethered balloons, inter alia. AD-619 695.

Ruffenach, Gene: Compatibility of Balloon Fabrics with Ammonia. GCA Viron Div. Report 3-177-03; February 1966. Final Report on Forest Service contract 19-50. Neoprene-nylon fabric and neoprene-adhesive seams had good life in NH_3 at 100% relative humidity.

Schrivner, John H. Jr, Captain USAF: The Military Use of Balloons and Dirigibles in the United States 1793 - 1963. Thesis for University of Oklahoma Graduate College, 1963.

Smalley, Justin H.: Balloon Design Data in Gore Length Units. AFCRL 65-447, June 1965.

U.S. Air Forces Historical Division: Barrage Balloon Development In the United States Army Air Corps 1923 - 1942. By Assistant Chief of Air Staff, Intelligence, Historical Division, Army Air Forces Historical Studies; No. 3, Dec. 1943.

Upson, Ralph H., Chandler, Charles deForest: Free and Captive Balloons. New York, The Ronald Press, 1926. Fully covers technology [illegible] to its date, but without much detailed aerodynamic or mathematical detail. Includes extensive section on fabric for gas envelopes.

Weidner, George E.: Flying Accessories, Tandem, B.B. V.L.A. U.S. Army Corps of Engineers, Fort Belvoir, Va., Report No. 795, Feb. 15, 1944, ATI 98455.

Wilcox, R.C.: Report on Generation of Hydrogen for Barrage Balloons. National Defense Research Committee, Office of Scientific Research and Development, Serial No. 228, April 1942, ATI.

Young, Edward F., Captain USAF: Tethered Balloons: Present and Future. AIAA 2nd Aerodynamic Deceleration Systems, Conference, El Centro, Calif., AIAA Paper No. 68-941, Sept. 25, 1968.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Goodyear Aerospace Corporation Akron, Ohio 44315	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

TETHERED BALLOON HANDBOOK (REVISED)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific. Final. 1 May 1968 - 31 December 1968. Approved 7 Feb. 1969

5. AUTHOR(S) (First name, middle initial, last name)

Philip F. Myers

November 1969	7a. TOTAL NO. OF PAGES 228	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. F19628-68-C-0311 b. PROJECT NO., Task No., Work Unit No. 6665-07-01 c. DoD Element 6340917F d. DoD Subelement 636000	9a. ORIGINATOR'S REPORT NUMBER(S) GER 14142 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-69-0017(I)	

10. DISTRIBUTION STATEMENT

1 - Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (CRE) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

The Tethered Balloon Handbook is a single volume reference covering the history, development, applications, and listings of available modern equipment for tethered balloon activities of an engineering or scientific nature.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aerostatics						
Balloons						
Balloon Envelope Materials						
Balloon Handling						
Balloon Instrumentation						
Balloon Operating Sites						
Cables						
Captive Balloons						
Kite Balloons						
Lifting Gases						
Tethered Balloons						
Tethers						
Winches						